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MICROGRAVITY IGNITION EXPERIMENT

Worcester Polytechnic Institute
Mechanical Engineering Department
Worcester, MA

Professor Vahid Motevalli
William Elliott, Teaching Assistant
Keith Garrant, Ryan Marcotte

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Abstract

The purpose of this project is to develop a flight ready apparatus of the microgravity ignition experiment for the GASCan II program. This involved redesigning, testing, and making final modifications to the existing apparatus. The microgravity ignition experiment is intended to test the effect of microgravity on the time to ignition of a sample of α-cellulose paper. An infrared heat lamp is used to heat the paper sample within a sealed canister. The interior of the canister was redesigned to increase stability and minimize conductive heat transfer to the sample. This design was fabricated and tested and a heat transfer model of the paper sample was developed.

Authorship

We feel that both of us contributed equally to all portions of this project.

Acknowledgements

We would like to thank the many people who assisted us with our project:

Professor Vahid Motevalli, our advisor

Professor Jim Duckworth and Ryan Marcotte, for the electrical engineering portion of this project

Professor Bill Durgin, for his valuable assistance

William J. Elliot, for his time and patience

Todd Billings, for his time and effort

MITRE Corporation

Table of Contents

Nomenclature

α - absorptivity of paper

C - specific heat

d - paper thickness

E_{stored} - Energy stored in paper

ϵ - emissivity

I - heat flux

$\dot{q}_{conv}$ - *convective heat transfer*

$\dot{q}_{cond}$ - *conductive heat transfer*

$\dot{q}_{rad}$ - *radiative heat transfer*

ρ - density

σ - Boltzman constant

T_s - sample temperature

T_∞ - ambient temperature

t - time

Introduction

One of the most important issues for long term space occupation, such as in a space station, is fire safety. The very low gravity condition in space can drastically affect the phenomena of combustion and fire. In order to maintain fire safety, the initiation of the combustion phenomenon, ignition, must be understood. While ignition has been studied, the effect of a microgravity environment on the ignition process is not completely understood. The purpose of this project is to determine how the microgravity environment affects ignition time.

A major factor in the ignition process is heat transfer. As a fuel source is heated, products are released due to molecular breakdown of the sample. This process is referred to as pyrolysis. These products mix with the surrounding air and, when a sufficient amount of heat has been transferred to the sample, make ignition possible.

There are three ways in which heat is transferred into or away from an object. These are radiation, conduction, and convection. Heat may be transmitted by the emission and absorption of radiation. In addition to heat transfer due to radiation, there is heat transfer due to the contact of two objects of different temperatures. This is referred to as conductive heat transfer. Finally, heat may be transferred by convection currents in the air.

Convection currents result from buoyancy forces caused by earth's gravity. When a substance is hotter than the surrounding air, the temperature of the air near the surface of the substance increases because of the transfer of heat. Convection currents force the less dense heated air to rise away from the hot substance and the cooler, more dense air to sink to the surface of the substance, as shown in figure 1.

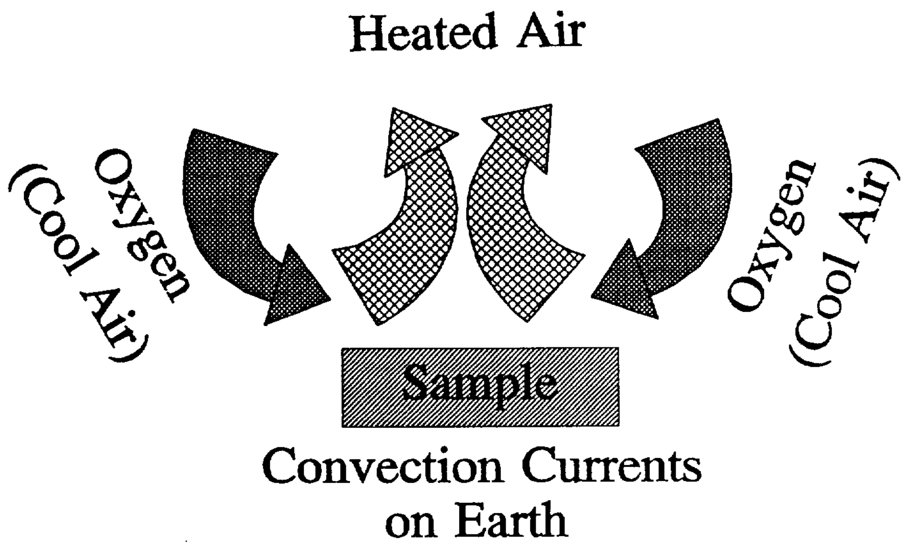


Figure 1

Due to the lack of gravity in a microgravity environment, convection currents are not present. This lack of convection currents causes a cloud of heated air and pyrolysis products to form around the object, as shown in figure 2. This will cause a reduction in the heat transferred away from the object, increasing the object's temperature, therefore decreasing the time to ignition. The absence of convection currents also prevents the cooler, oxygen rich air from sinking towards the object. It is possible that the lack of this oxygen may stop ignition from occurring at all. The purpose of this experiment is to determine how these conflicting processes affect the time to ignition by collecting and comparing data regarding ignition in microgravity and on earth, and analyzing the results.

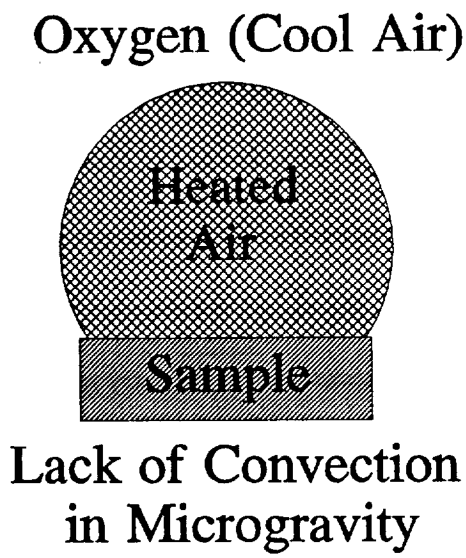


Figure 2

Previous Projects

The microgravity ignition experiment is a continuing project. The first Major Qualifying Project (MQP), on this project was completed in 1986. This project determined the purpose of the experiment and resulted in construction of a prototype. In addition, various types of sensors were investigated for the measurement of flux, temperature, and ignition (Blacker, et al., 1986).

Later groups considered many different substances for the test sample. Eventually, National Bureau of Standards α-cellulose (paper) was selected, for its relative consistency. This was chosen because the properties of the paper were relatively constant, and the heat required to ignite the paper is not excessive (Forget, et al., 1990)

The initial combustion chamber was redesigned by the 1990 MQP group. The 1991 MQP group investigated the reliability of the equipment for the experiment. They discovered that the moisture content of the α-cellulose paper affected the time to ignition. A procedure for drying the test sample was then developed. In addition to this, and their development of the alignment apparatus and procedure, low temperature testing of the experimental components was conducted (Forget, et al. 1990; Maranghides, Roy, 1991). Modifications in the chamber have been made by this years team.

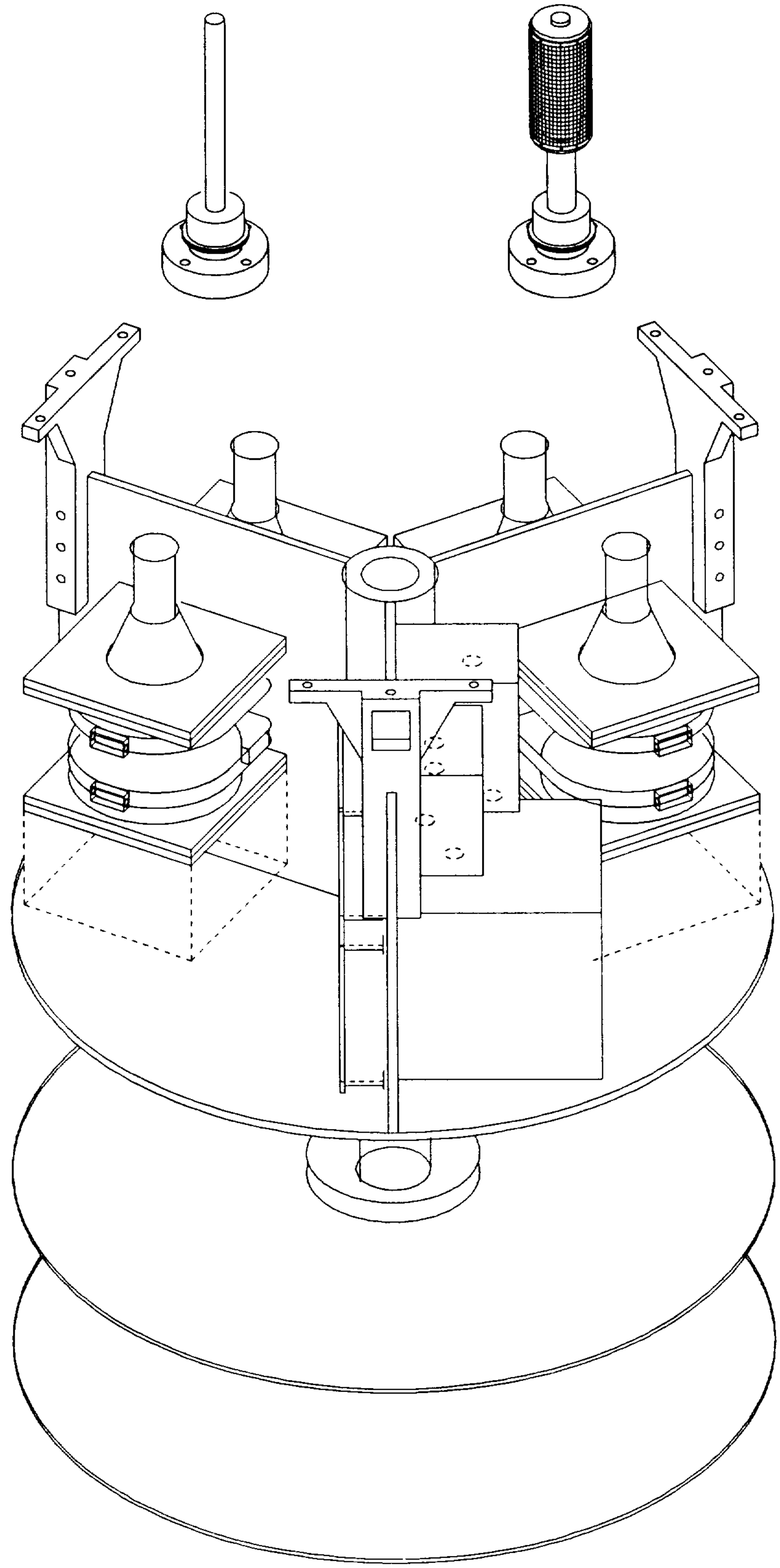
Previous projects also considered many possible heat sources. An Argus type 44 infrared heat lamp with a gold plated reflector was chosen for the heat source. The 1991 MQP group designed and fabricated a lamp alignment apparatus. Using this device they developed a procedure for aligning the bulb both horizontally and vertically. This focuses the lamp and allows the point of maximum heat flux to be concentrated on the test sample (Maranghides, Roy, 1991).

Jeff Goldmeer's master's thesis developed a heat transfer model for a copper plate. This model had problems finding the convection coefficient because of the difficulty in modeling the heat transfer caused by the contact of the copper with the teflon backplate (Goldmeer, 1991). This model was used as a basis for the heat transfer model of α-cellulose paper.

GASCan II

Gascan II is an is a group of three experiments which will be launched aboard a Get Away Special Canister in the cargo bay on the space shuttle. In addition to the microgravity ignition experiment there will be an experiment to study vortex formation in simulated gravity levels and experiment to study the properties of the ionosphere. Gascan II is scheduled to be flight ready next year.

Figure 3 illustrates the placement of the four microgravity ignition canisters inside the GASCan. The canisters will be clamped to the interior flanges of the support structure. The printed circuit board containing the experiment controller is bolted to one of the interior flanges.



GASCan II

Figure 3

Experimental Apparatus

Chamber

The experiment consists of four combustion chambers. The combustion chamber is an aluminum cylinder to which four aluminum plates are mounted. Plates one and two mount the infrared heat lamp on the cylinder. Plates three and four are used to position a teflon holder. This holder supports the paper sample and all sensors mounted within the ignition chamber. Plate four also contains ports for a pressure transducer and two purging valves. The chamber is designed to be airtight and contain dry air at slightly higher than atmospheric pressure. The plans for the four endplates are shown below. Figure 4 shows a diagram of the total configuration of the canister.

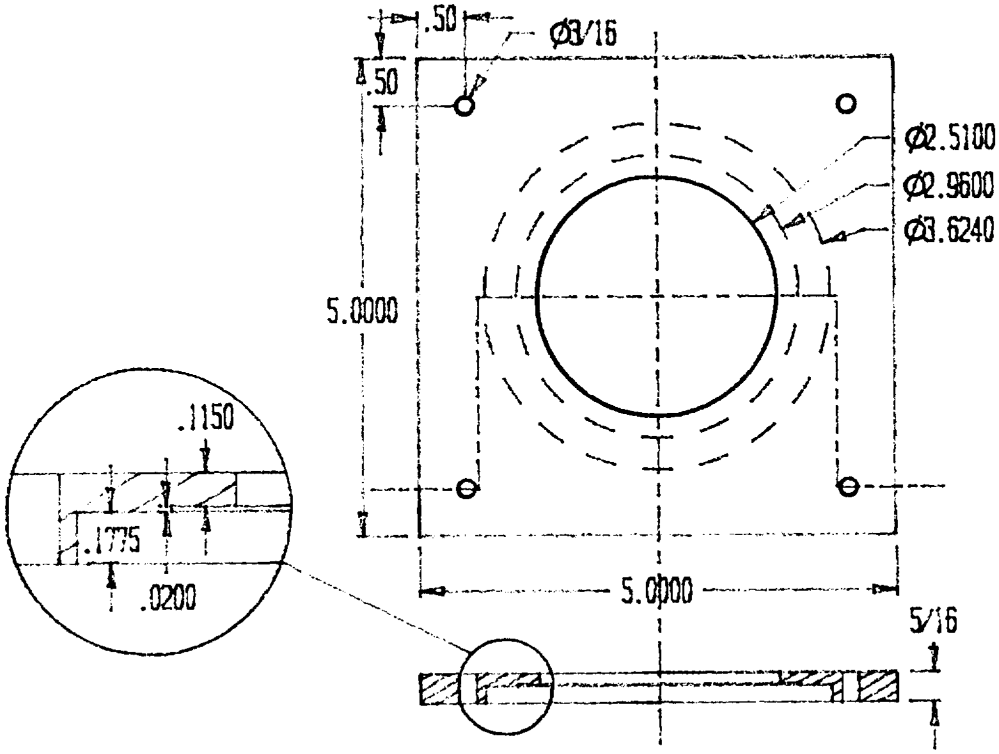
Heat Lamp

The heat lamp is an Argus model 44 infrared heat lamp. It consists of a 250 watt bulb which requires a 24 volts to operate. This bulb is mounted within a gold-plated parabolic reflector. The bulb and reflector are separated from the experimental chamber with a circular quartz window.

Instrumentation

Ion Sensor

There are currently four types of sensors that are used in the experiment. One of these is an ion sensor. Three of the canisters which contain a paper sample also contain the ion sensor. The ion sensor is used to determine when ignition occurs. It consists of two stainless steel wires which are mounted above the test sample forming an open circuit. When the sample burns ions are produced which allows a current to pass



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WPI Advanced Space Design Center

MITRE/WPI NASA -- USRA

☐ Flight ☑ Prototype ☐ Other ____________

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Unless otherwise specified:	Shop:				
	ICWG:				
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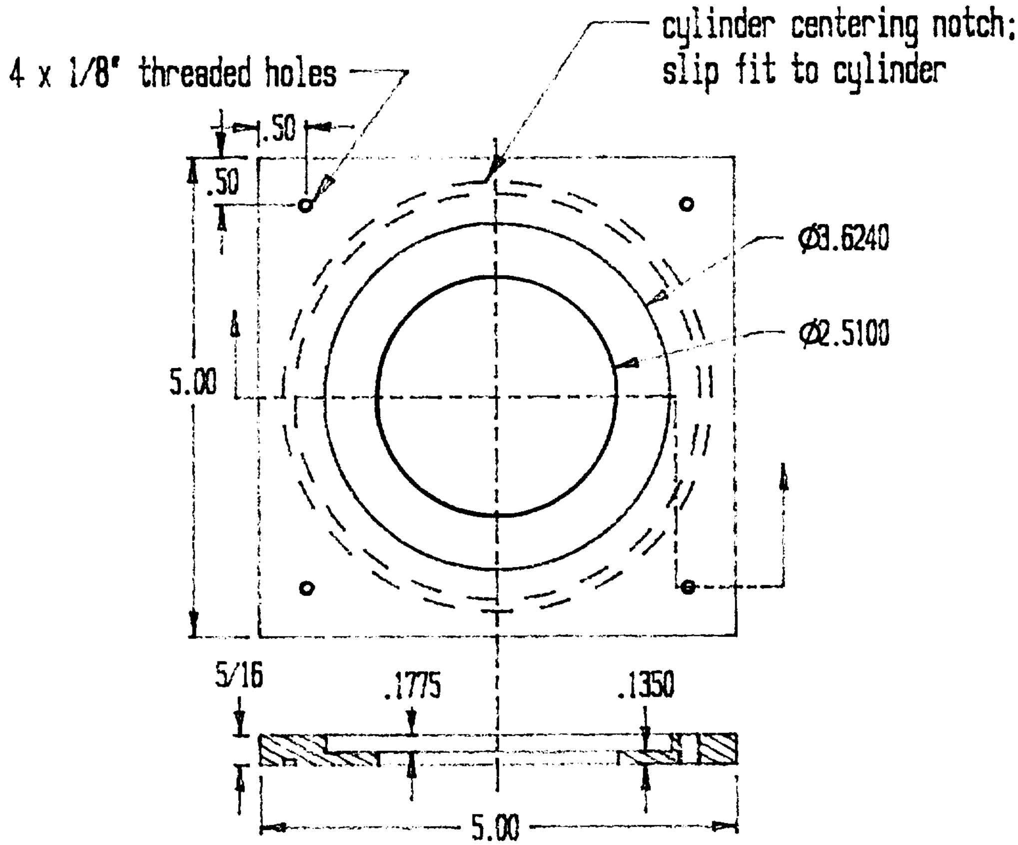

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MITRE/WPI NASA – USRA

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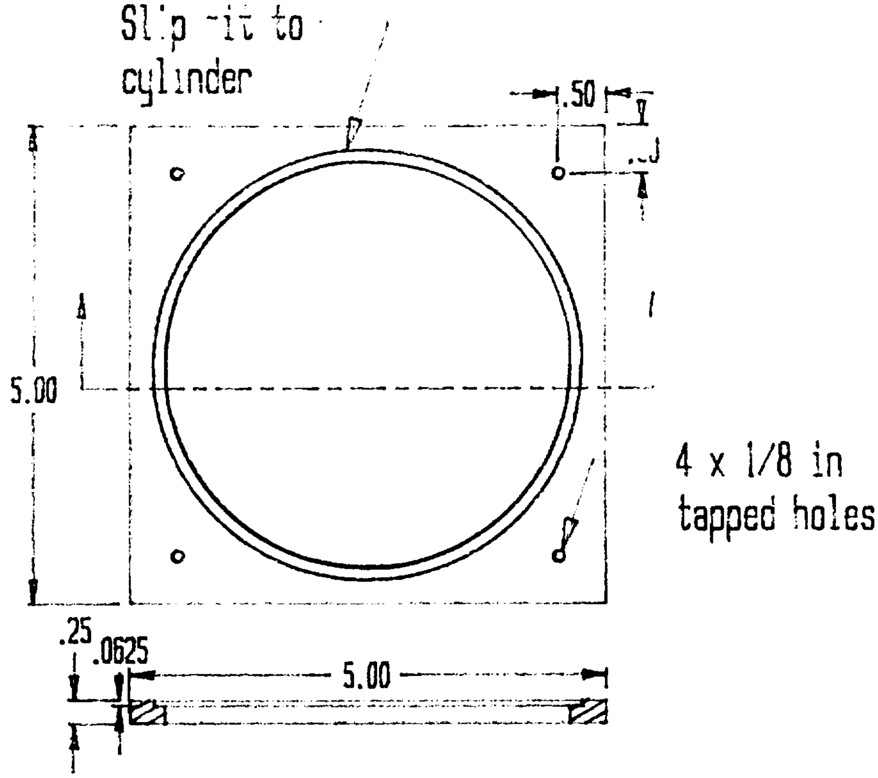

WPI Advanced Space Design Center

MITRE/WPI NASA – USRA

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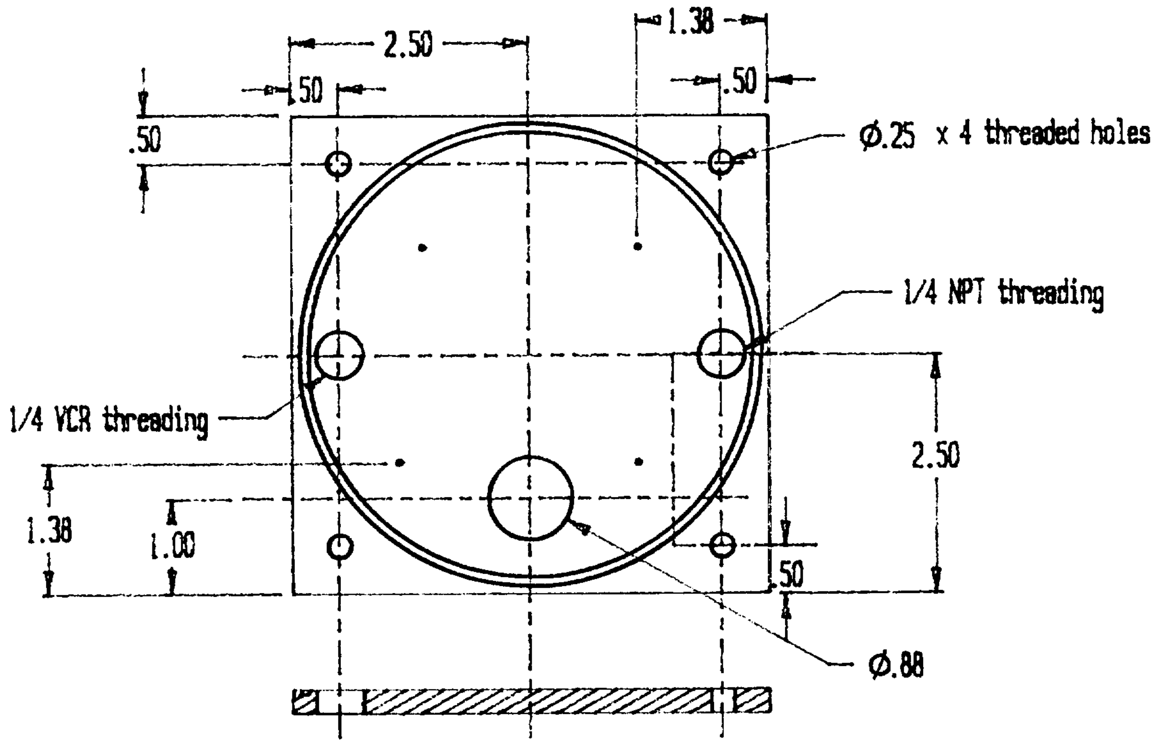

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WPI Advanced Space Design Center

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☐ Flight ☐ Prototype ☐ Other

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Unless otherwise specified:	Shop:		Units: ☒in ☐mm
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Angular Dim ±	Advisor:		Drawing Number: GS-II-
	Approved:		Rev:

between the two wires, completing the circuit. When the circuit is completed, a voltage is produced indicating that ignition has occurred.

Thermocouples

Another type of sensor used is a thermocouple. The thermocouple are used to measure temperature. Three of the canisters contain four thermocouple in each chamber. One of the thermocouple is used to measure the backface temperature of the sample. The other three are set up in a thermocouple array to determine the temperature at different distances from the test sample. This data can be used to approximate the temperature gradient within the canister.

Pressure Transducer

The pressure in these three canisters is monitored throughout the experiment with a pressure transducer. The data provided by the pressure transducer can be used to determine the pressure rise caused by the lamp and/or pyrolysis at any point during the experiment. This is useful in more complete thermodynamic analysis. The data can also be used to determine if the seal of the canister was intact at the beginning of the experiment . This is necessary in order to establish that the environment inside the canister contained only the dry air with which it was purged.

Flux Meter

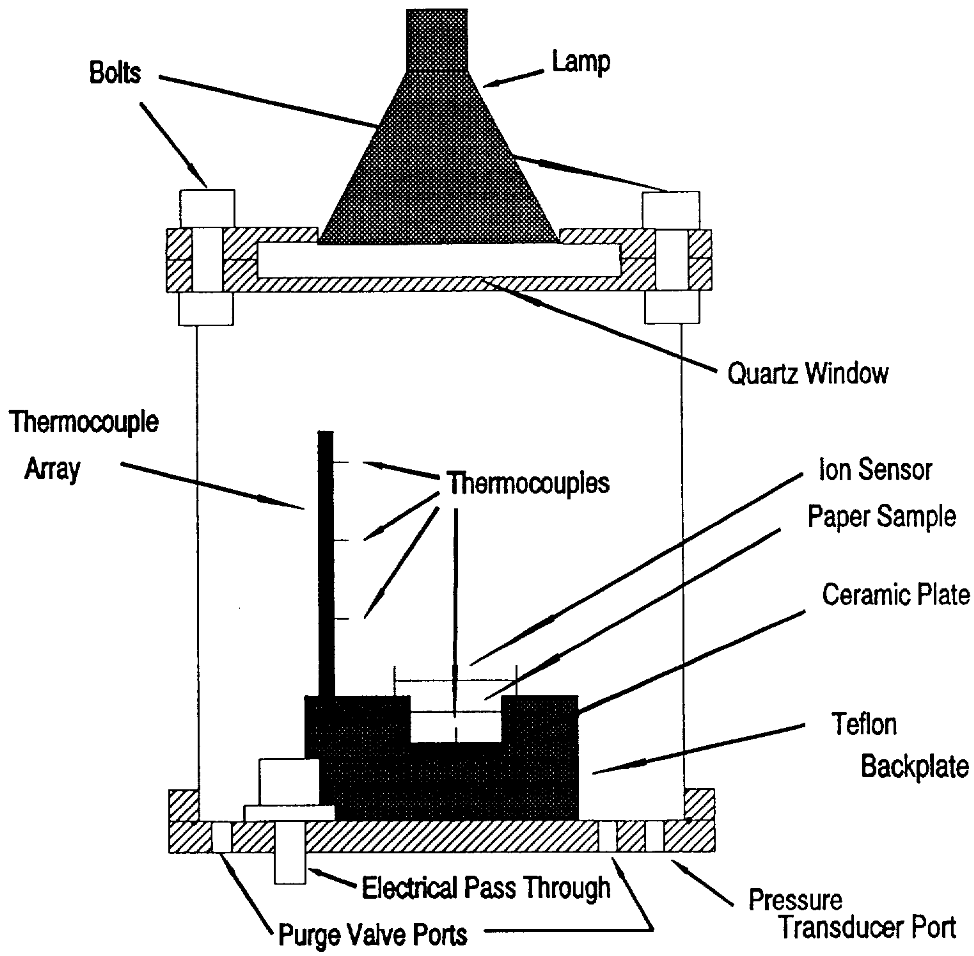
One canister will not contain a sample of α-cellulose paper. It will instead contain a gardon gage. This will be used to measure the flux output of a bulb in microgravity. This was done because the flux output of the lamp may be different due to the lack of convection currents within the bulb, in microgravity. This canister will not contain an ion sensor, a sample backface thermocouple, a thermocouple array, a pressure transducer, or purge valves.

Purging Apparatus

In order to produce repeatable results, it required that a dry environment be maintained within the canister. This is because the paper sample would absorb any moisture present in the air which would affect the time to ignition of that sample. It was decided to provide this dry environment by purging the sealed canister with dry air. This method consists of two valves, one inlet valve and one outlet valve, mounted directly to the bottom aluminum plate. The three canisters which contain the paper sample also contain these valves.

Data Acquisition

The data acquisition system developed this year in Marcotte's MQP controls the experiment sequencing. In addition, it stores the results of the experiment in non-volatile EE PROMS. This allows the data to be maintained even when the GASCan batteries are drained. The data acquisition system also contains the preflight diagnostics. Using a personal computer all of the electric systems of the experiment can be tested. The chips for the data acquisition system are rated to -25 degrees C.



Experimental Canister

Figure 4

Sequence of Experiment in Space

The three experiments contained within the GASCan II will be run in a sequence, with microgravity ignition being the first experiment in the progression. The sequence will be started by an astronaut at the beginning of the first sleep period. Running the experiments during the sleep period will provide an environment with the least activity and the lowest acceleration. The astronaut will flip a switch, signaling the power up of the GASCan. Figure 5 illustrates the sequence of the microgravity ignition experiment.

After the GASCan itself has been powered up, power will be provided to canister one of microgravity ignition. This is the canister that contains the gardon gage instead of the paper sample. The lamp will be turned on and run for 15 seconds. The software designed by the electrical engineering portion of the team will sample the data for the duration of the run (Marcotte, Ryan, 1992). After 15 seconds the software will turn the lamp of canister one off and pause for 5 seconds before signaling canister two.

When the software controlling canister two receives its signal, the lamp is turned on, sampling from all the sensors begins, and a timer is started. This continues until the ion sensor detects ignition of the paper sample. At this point, the lamp will be turned off. Sampling of the sensors will continue until the timer, which was started at the beginning of the run, reads 30 seconds. Canister two is then powered down. If ignition is not detected within 30 seconds, the lamp will be turned off and sampling will stop at the 30 second mark. Canister three and four are run identically to canister two.

Canister one will be run again 5 seconds after the power down of canister four. It will be run following the same procedure that was used during its first run. The data from this run will be compared with the data from the first run to determine if drainage of the batteries has caused any changes in the flux output of the lamp.

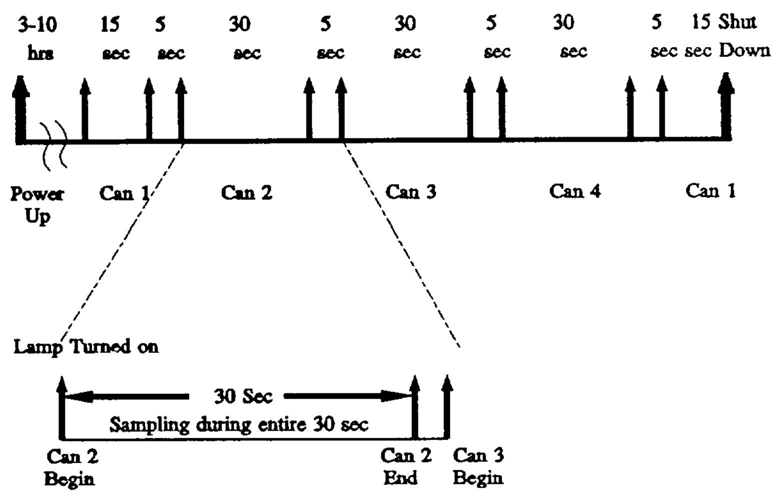


Figure 5 - Experimental Sequence

Heat Transfer Model

A mathematical model of the heat transfer in the canister for a copper plate was developed in Jeff Goldmeer's master's thesis (Goldmeer, 1991). This model was redone to take into account some changes in the chamber design and the use of α-cellulose paper. First, the energy balance was considered.

$$E_{stored}=\alpha I-\dot{q}_{cond}-\dot{q}_{conv}-\dot{q}_{rad} \tag{1}$$

The energy stored by the paper is:

$$E_{stored}=\rho c d\frac{\delta T_s}{\delta t} \tag{2}$$

The heat transfer due to convection is:

$$\dot{q}_{conv}=\bar{h}(T_s-T_\infty) \tag{3}$$

The heat transfer due to radiation is:

$$\dot{q}_{rad}=\sigma\epsilon(T_s^4-T_\infty^4) \tag{4}$$

The teflon backing was redesigned in order to eliminate conductive heat transfer with the sample, which was a major problem with the Goldmeer model. Because of this, conductive transfer can be ignored. Combining this fact with equations (1), (2), (3), and (4) yields:

$$\rho c d \frac{\delta T_s}{\delta t} = \alpha I - \bar{h}(T_s - T_\infty) - \sigma \epsilon (T_s^4 - T_\infty^4) \tag{5}$$

Finally, solving this equation for h results in (Goldmeer, 1991):

$$\bar{h} = \frac{\alpha I - \rho c d \frac{\delta T_s}{\delta t} - \sigma \epsilon (T_s^4 - T_\infty^4)}{T_s - T_\infty} \tag{6}$$

In addition the following equation was used for the heat flux from the lamp with I_0 and τ being constants (Hagdoust, 1991):

$$I = I_0 [\ (1 - e^{\frac{-t}{\tau_l}}) + e^{\frac{-t(\tau_l - \tau_t)}{(\tau_l * \tau_t)}} - e^{\frac{-t}{\tau_t}}\ ] \tag{7}$$

In order to predict the temperature change of the sample in microgravity, the convection coefficient was set to zero and was solved using Lotus 123. A graph of the results for the sample temperature is shown in figure 6. Figure 7 displays a graph of the flux output of the lamp and the reradiation loss of the paper.

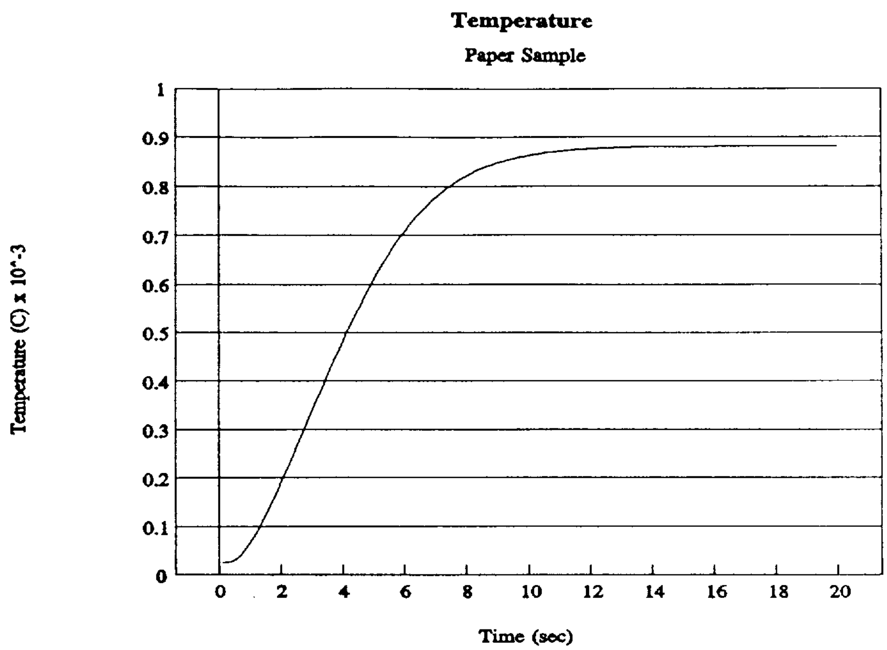


Figure 6

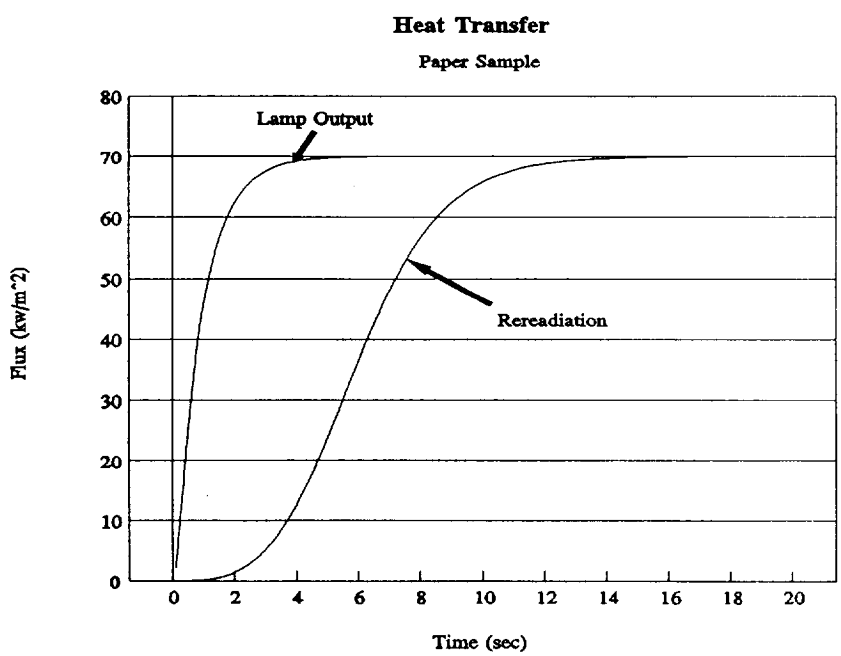


Figure 7

According to figure 6, the sample will reach its pyrolysis temperature of approximately 625 degrees C at approximately 5.5 seconds. The 1991 team determined that the average time to ignition on earth using the baseplate with conduction was 13 seconds. This predicted decrease in the ignition time is a result of the lack of convection currents and the assumption of zero conduction loss. If the lack of convective heat transfer overpowers the lack of oxygen supply, then this prediction will be accurate. However, this model is not valid if the sample does not ignite because of the oxygen deficiency.

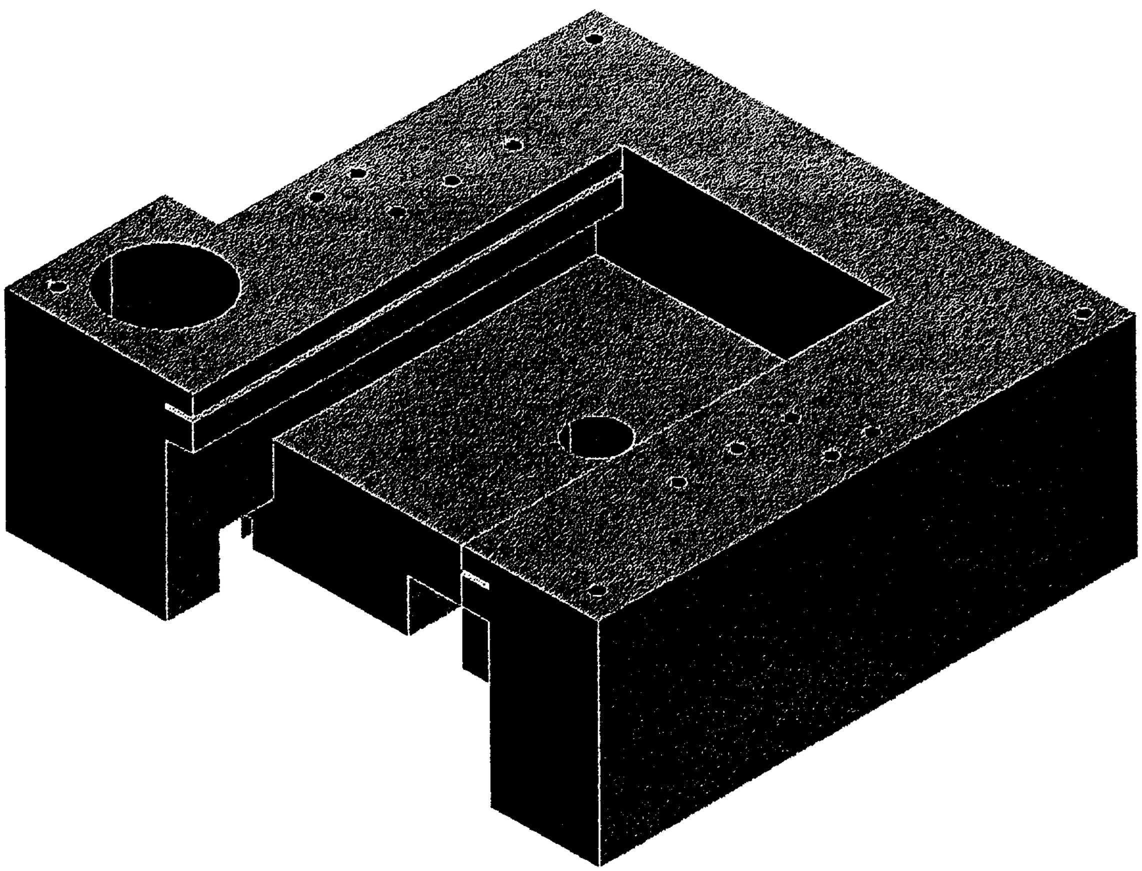
Figure 7 shows Hagdoust's estimate of the warming curve of the lamp. In addition, if the lamp is continuously operated, it is predicted that a steady state condition will be reached at approximately 14 seconds. At this point, the heat flux from the lamp equals the reradiation loss from the sample. This results in the flattening of the curve seen in figure 7.

Experiment Revisions

At the beginning of this project, the design was reviewed and it was determined that some portions of the design needed to be reevaluated. The areas were: teflon plate, ion sensor, backplate material, thermocouple array, pressure transducer, purging mechanism.

In order to make it possible to build a flight-ready prototype of the experimental canister, the existing design was modified and components that can withstand the rigors of the mission were chosen. The first objective in this was to revise the teflon backplate. In revising the backplate, the issues of the sample holder and the ion sensor were addressed. The sample holder was redesigned in order to reduce the contact between the paper and the backplate and to facilitate removing and replacing the paper sample. The drawing of the design is below in figures 8 and 9. The new design consists of a slot cut into the back plate so that the paper sample can simply be slid into the proper position. This minimizes the contact between the teflon and the paper, therefore minimizing the conductive heat transfer between the two. Combining this with the fact that teflon has very low thermal conductivity allows the heat conducted to the sample to be neglected. This design also allows the paper sample to be replaced without interfering with the ion sensor wires, as this groove provides enough room to maneuver below the ion sensor.

The matter of the distance between the wires of the ion sensor was also examined. It was found that this issue was addressed in the 1991 MQP. The results showed that equidistant placement of the wires produce the most repeatable outcomes. In the new design, the ion sensor wires are positioned so that they are equidistant at a distance of



Teflon Backplate

Figure 8

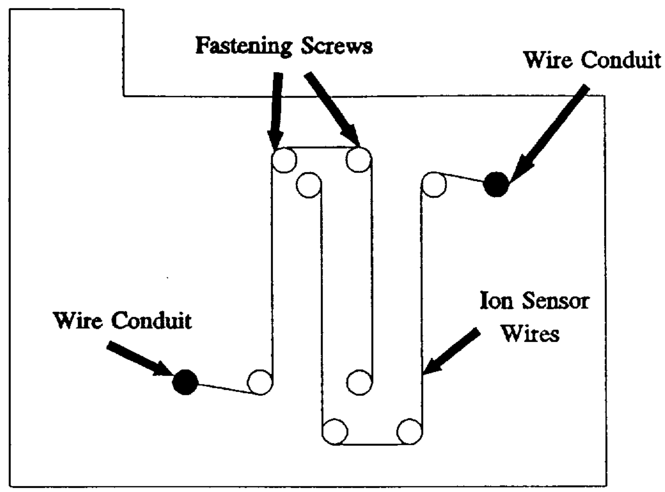


Figure 10 - Ion Sensor Configuration

1/8 ". A diagram of the wire configuration is shown in figure 10.

The material used for the backplate, teflon, cannot withstand the extreme high temperatures that are reached at the sample backface. In order to provide for this, a ceramic plate is secured in a groove below the paper sample with Omegabond 100 epoxy. This plate measures 1.5" L x 1.5" W x 0.125" thickness. Aluminum oxide was the ceramic chosen because it is very non-conductive and can withstand the temperatures that will be reached during the experiment. Appendix A contains a list of the properties of aluminum oxide.

The thermocouple array was redesigned in order to increase stability, improve construction, and simplify testing of the structure. The new design consists of a 3" long x 0.5" diameter steel tube with a 0.13" slot cut down one side and a portion cut out of the tube opposite to this slot. The tube is threaded on one end. The threading permits the tube to be threaded directly into the teflon backplate. There are three small steel cylinders that slide along the interior length of the tube. These cylinders contain a 0.125" ceramic bead through which the thermocouple wires are threaded. A copper arc-shaped section is fastened from the exterior of the tube to the interior section in order to hold the thermocouple in the desired position. Each of the three thermocouple are held in this fashion. This facilitates the testing of the thermocouple at varying distances along the length of the tube. The teflon shielded thermocouple wires are run up the outside of the tube and through the ceramic beads to the interior of the tube. The drawings of these components are below in Figures 11 - 13.

Another issue that was addressed was that of the pressure transducer. The previously chosen transducer is both too large for the GASCan and cannot endure the temperatures that may be reached during flight. An Entran EPX series miniature threaded pressure transducer was selected. It has a compensated temperature range from zero to sixty degrees celsius. The transducer is extremely small protruding from the back of the canister only 0.75 inches. Its specifications are in Appendix D - Part Sheets.

The next step in modifying the prototype was to decide upon a method of purging the combustion chambers. This method consists of two one-way valves. The inlet valve is a stainless steel SS-4C-VCR-10 NUPRO "C" Series check valve. The use of a check valve rather than a manual valve will simplify preflight procedures by eliminating the need to manually open and close the valve. This valve has a nominal cracking pressure

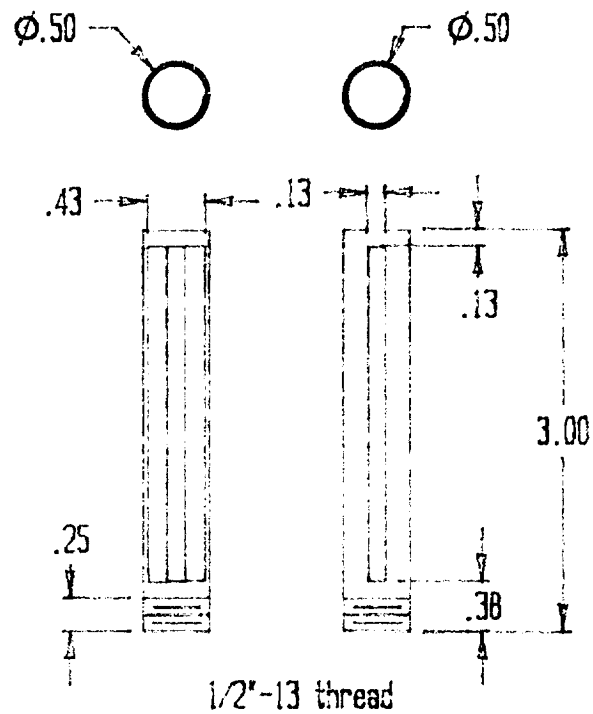


Figure 11

		Steel	WPI Advanced Space Design Center MITRE/WPI NASA – USRA			
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Number Required:			Checked:		Scale:	Units: ☒ in ☐ mm — A
Unless otherwise specified:			Shop:			
			TCWG:			
Machine Dim ±			Advisor:		Drawing Number:	Rev:
Angular Dim ±			Approved:		GS-II-	

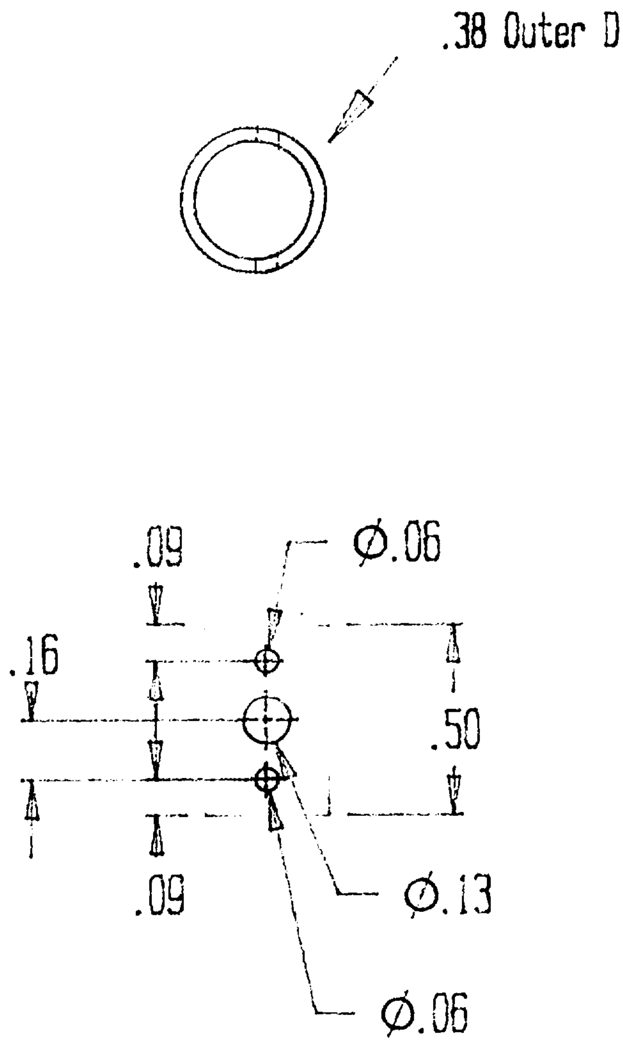

Figure 12

WPI Advanced Space Design Center

MITRE/WPI NASA – USRA

ITEM	# Req.	Material
		Steel

☐ Flight ☒ Prototype ☐ Other

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Next Higher Assy:
Number Required:
Unless otherwise specified:
Machine Dim ±
Angular Dim ±

Signatures	Date
Drawn By:	
Checked:	
Shop:	
ICWG:	
Advisor:	
Approved:	

Part Name: Interior Thermocouple Array Part

Scale:

Units: ☒ in ☐ mm

A

Drawing Number: GS-II- 92-TCPT1

Rev:

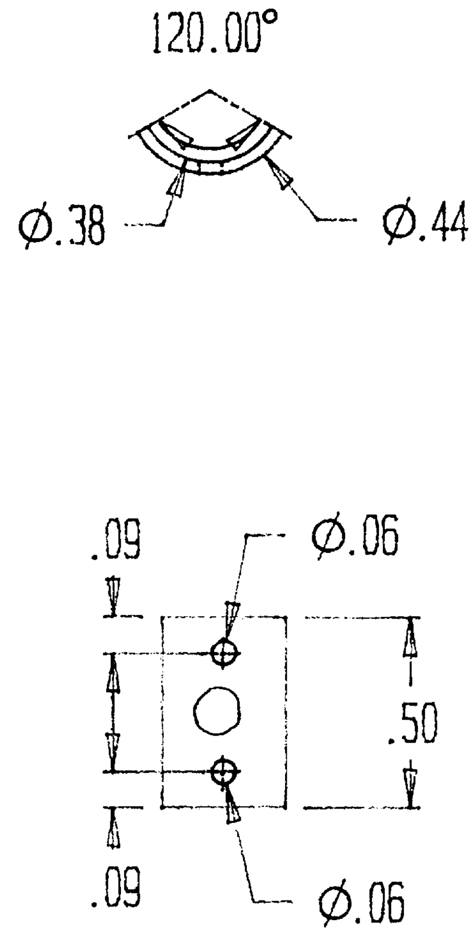

Figure 13

		Brass	WPI Advanced Space Design Center MITRE/WPI NASA – USRA
ITEM	# Req.	Material	☐ Flight ☒ Prototype ☐ Other

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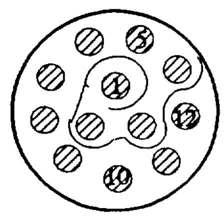
Number Required:	Checked:		Scale: / Units: ☒in ☐mm / A
Unless otherwise specified:	Shop:		
	ICWG:		
Machine Dim ±	Advisor:		Drawing Number: / Rev:
Angular Dim ±	Approved:		GS-II- 92-TCPT2

and will be screwed directly into the bottom plate. The exit valve is a manual ·ss steel SS-4P-4M NUPRO "P" Series purge valve. This valve will also be ·d directly into the bottom plate. The specifications for both valves are shown in endix D - Part Sheets.



Top Thermocouple:	Yellow wire - pin 1 Red Wire - pin 2
Middle Thermocouple:	Yellow - pin 3 Red - pin 4
Bottom Thermocouple :	Yellow - pin 5 Red - pin 6
Ion Sensor:	Black - pin 7 Red - pin 8
Backface Thermocouple:	Yellow - pin 9 Red - pin 10

Figure 15 - Pin Diagram

It was also determined that a hermetically sealed electrical connector was required. Various suppliers of military specification hermetic connectors were contacted but sealed connectors were not kept in stock and the cost of producing the connectors was prohibitive. It was decided to continue using the Omega connector previously selected, in a version with only 12 pins. The pin arrangement is shown in figure 14. Although its leakage rate has not been tested, it is the only viable alternative. The specifications for the connector are shown in Appendix D - Part Sheets.

Preflight Procedure

In addition to the design changes the procedure to prepare the experiment for launch had to be developed, using the general preflight procedure developed by the 1990-1991 MQP group. This preflight procedure insures that the experiment will be properly prepared and that all components are in working order. Testing of the preflight procedure by a person not affiliated with the microgravity experiment must be conducted to confirm that the procedure is clear and easy to follow.

It is assumed that certain tasks will be completed prior to the experiment being shipped to NASA, where the final preflight procedure will take place. The assumptions are that all ground testing has been completed, the canister walls and all its' components have been cleaned, the ion sensor wires have been changed, and paper samples have been dried for use. Assuming all these tasks have been completed, the procedure is as follows:

1. Clean reflector, bulb, and quartz window *(indicates must wear rubber gloves)
2. Align lamp horizontally *

a. Stand alignment device on table and set platform to desired height using a ruler to measure it

b. Carefully place a flat piece of thermal paper in slot on platform with sensitive side up

c. Place ignition chamber on alignment device

d. Using a stopwatch to measure time, turn on power supply for desired amount of time

e. Remove chamber from alignment device

f. Carefully place grid over the platform

g. Determine center point of innermost circle, that is point of highest intensity

h. If center is not at desired position, adjust bulb and repeat procedure

3. Perform test of electronics

   a. Run test procedure through a PC

4. Mount paper sample *

   a. Remove old paper sample

   b. Slide properly dried paper sample into the sample groove in teflon backplate

5. Seal chamber

6. Purge chamber with dry air at positive pressure

   a. Open outlet valve

   b. Connect pressurized air container set at desired pressure to inlet valve

   c. Run for necessary time period

   d. Disconnect pressurized air container

   e. Close outlet valve when pressure inside chamber reaches desired level

7. Final test of electronics

8. Mount chamber on GAScan

Testing Procedure

Before the final flight ready canisters are built the prototype must be fully tested and refined. Procedures were developed for low temperature testing, and vibration testing.

<u>Low Temperature Testing</u>

During the course of the shuttle mission, the GAScan will experience temperatures lower than room temperature. Tests of the canister and the printed circuit board must be performed at lower temperatures in order to determine that all the components utilized in the experiment can withstand the temperatures that may be experienced during the mission.

Based upon the thermal model of GAScan II, the worst case temperature is expected to reach 280 degrees K after 20 hours of flight. For this reason it was decided that the low temperature tests can be done in a refrigerator, where temperatures will not fall below freezing.

The following procedure was used:

1. Run the experiment to insure that all components are in working order.
2. Replace the paper sample, seal the chamber, and purge it.
3. Place the chamber and the printed circuit board in the refrigerator for 24 hours.
4. Remove the chamber and the board and run the experiment to determine if all the components are still in working order.
5. If the experiment does not run properly, determine where the problem is and correct it.

6. Repeat this procedure at least two more times to check for repeatability.

Vibration Testing

Vibration tests of the canister and the printed circuit board must be performed to satisfy safety requirements set by NASA. These tests require that the experiment be vibrated at specified Hz levels to insure that the resulting acceleration does not exceed the safety level determined by NASA. The tests should be done using the following procedure:

1. Run the experiment twice and collect the data from these runs.
2. Replace the paper sample, seal the chamber, and purge it.
3. Place the canister and the printed circuit board on the shake table.
4. Run the shake table for 1 minute sweeping it from 20 to 80 Hz.
5. Record the acceleration during the run and compare it to appropriate section of the graph in Appendix F - Vibration Specifications. The acceleration must not exceed the levels of the graph or the experiment will not be considered safe.
6. Do this twice for each set of frequencies: 20 to 80 Hz
80 to 1000 Hz
1000 to 2000 Hz
7. After completing all the tests, run the experiment and collect the data to insure that all the components are still in working order. If there is a problem, determine where it is and correct it.
8. Compare the data from before the vibration test with that from after to check for repeatability.

Ground Based Data Acquisition

Once the prototype completes the low temperature and vibration testing acceptably, the design for the flight ready canister should be finalized. The prototype canister should then used to acquire ground-based data to test the mathematical model. The canister should be prepared for the testing using the preflight procedure for one canister.

Results

A baseline experiment was run using the new teflon backplate. Due to problems with the new experiment controller, Labtech Notebook was used to acquire the data. Figures 15 - 18 show the results of this experiment.

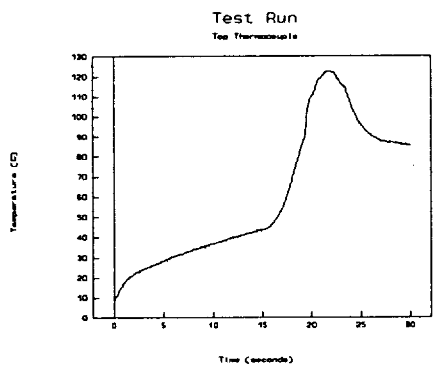


Figure 15 - Top Thermocouple

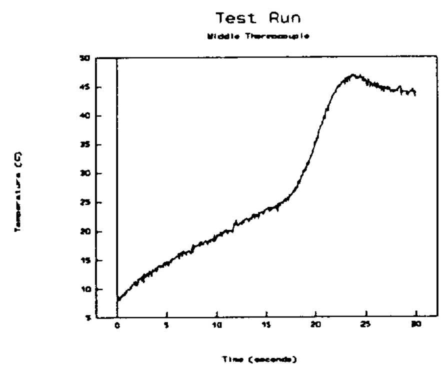


Figure 16 - Middle Thermocouple

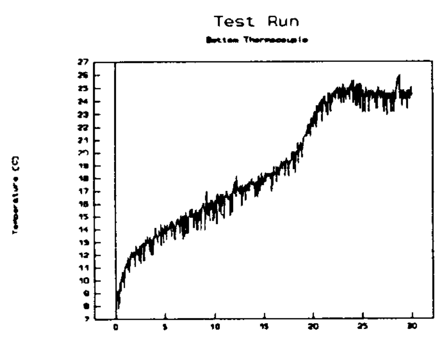


Figure 17 - Bottom Thermocouple

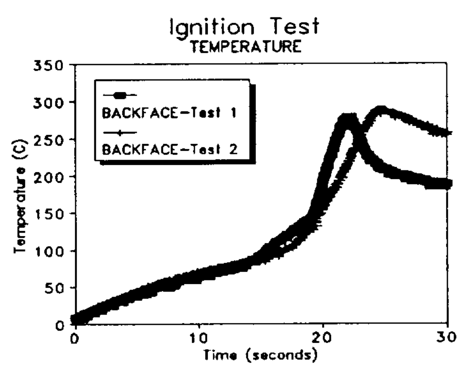


Figure 18 - Backface Thermocouple

These figures display the changes in temperature that occur within the canister and not the actual temperatures that are felt. The temperatures measured by the thermocouples are close to but slightly less than what was expected. It is possible that this is because the thermoucouple junctions are large and that the backface thermocouple was not in contact with the paper. However, the results show the expected trends. Figures 15 - 17 display the results for the thermocouple array from one run. Figure 18 illustrates the results for the backface thermocouple from two seperate tests. Both sets of results show the correct trend and show that the results obtained are very repeatable.

Recommendations

Next years project should complete the testing of the final prototype. Which should include low temperature and vibration testing. The design should be finalized, including setting the final heights of the thermocouple, as soon as possible. The flight ready canisters should then be built. In addition, procedures should be developed for cleaning the lamp reflector, because the procedure developed by the 1991 MQP group caused excessive wear of the reflective material. The preflight procedure developed this year should be tested and refined. Finally, the mathematical model should be further refined and verified by using ground based data.

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Appendix List

Appendix A - Aluminum Oxide Properties

Properties ... ceramics[a]

Material	Crystal structure	Theoretical density (Mg/m^3)	Knoop or Vickers hardness (GPa)	Transverse rupture strength (MPa)	Fracture toughness (K_{IC}) ($MPa \cdot m^{1/2}$)	Young's modulus (GPa)	Poisson's ratio	Thermal expansion ($\times 10^{-6}$ K^{-1})	Thermal conductivity [$W/(m \cdot K)$]	Specific heat [$J(Kg \cdot K)$]	Emittance[b]	Thermal shock resistance parameter[c]
Glass ceramics	Variable	2.4–5.9	6–7	70–350	2.4	83–138	0.24	5–17	2.0–5.4 at 400 K 2.7–3.0 at 1200 K	795–1298	0.9 at 300 K (T)	1.2[d]
Pyrex glass	Amorphous	2.52	5	69	0.75	70	0.2	4.6	1.3 at 400 K 1.7 at 800 K	335 at 100 K 1170 at 700 K	0.85 at 100 K (N) 0.85 at 900 K (N) 0.75 at 1100 K (N)	0.2
TiO_2	Rutile tetragonal Anatase tetragonal Brookite orthorhombic	4.25 3.84 4.17	7–11	69–103	2.5	283	0.28	9.4	8.8 at 400 K 3.3 at 1400 K	799 at 400 K 920 at 1700 K	0.83 at 450 K (T) 0.89 at 1300 K (T)	0.2
Al_2O_3	Hexagonal	3.97	18–23	276–1034	2.7–4.2	380	0.26	7.2–8.6	27.2 at 400 K 5.8 at 1400 K	1088	0.75 at 100 K (N) 0.53 at 1000 K (N) 0.41 at 1600 K (N)	6.5
Cr_2O_3	Hexagonal	5.21	29	>262	3.9	>103		7.5	10–33 at 350 K	670 at 300 K 837 at 1000 K 879 at 1600 K	0.69 (N) 0.91 (N)	2.7
Mullite	Orthorhombic	2.8		185	2.2	145	0.25	5.7	5.2 at 400 K 3.3 at 1400 K	1046	0.5 at 1200 K (N) 0.65 at 1550 K (N)	0.9
Partially stabilized ZrO_2	Cubic, monoclinic, tetragonal	5.70–5.75	10–11	600–700	8–9 at 293 K 6–6.5 at 723 K 5 at 1073 K	205	0.23	8.9–10.6	1.8–2.2	400		0.5
Fully stabilized ZrO_2	Cubic	5.56–6.1	10–15	245	2.8	97–207	0.23–0.32	13.5	1.7 at 400 K 1.9 at 1600 K	502 at 400 K 669 at 2400 K	0.82 at 0 K (N) 0.4 at 1200 K (N) 0.5 at 2000 K (N)	0.8
Plasma-sprayed ZrO_2	Cubic, monoclinic, tetragonal	5.6–5.7		6–80	1.3–3.2	48 21 at 1373 K	0.25	7.6–10.5	0.69–2.4		0.61–0.68 at 700 K (T) 0.25–0.4 at 2800 K (T)	0.2
CeO_2	Cubic	7.28				172	0.27–0.31	13	9.6 at 400 K 1.2 at 1400 K	370 at 300 K 520 at 1200 K	0.65 at 1300 K (T) 0.45 at 1550 K (T) 0.40 at 1800 K (T)	
TiB_2	Hexagonal	4.5–4.54	15–45	700–1000	6–8	514–574	0.09–0.13	8.1	65–120 at 300 K 33–80 at 1100 K 54–122 at 2300 K	632 at 300 K 1155 at 1400 K	0.8 at 1000 K (N) 0.85 at 1400 K (N) 0.4 at 2800 K (N)	21
TiC	Cubic	4.92	28–35	241–276		460	0.19	7.4–8.6	33 at 400 K 43 at 1400 K	544 at 293 K 1046 at 1366 K	0.5 at 800 K (N) 0.85 at 1500 K (N) 0.38 at 2800 K (N)	2.2
TaC	Cubic	14.4–14.5	16–24	97–290		285	0.24	6.7	32 at 400 K 40 at 1400 K	167 at 273 K 293 at 1366 K	0.2 at 1600 K (N) 0.33 at 3000 K (N)	3.7
Cr_3C_2	Orthorhombic	6.70	10–18	49		373		9.8	19	502 at 273 K 837 at 811 K		0.2
Cemented carbides	Variable	5.8–15.2	8–20	758–3275	5–18	396–654	0.2–0.29	4.0–8.3	16.3–119	197–544		13[e]
SiC	α hexagonal β cubic	3.21 3.21	20–30	Sintered 96–520 at 300 K 250 at 1273 K Hot pressed 230–825 at 300 K 398–743 at 1273 K 1034–1380 at 300 K 2060–2400 at 1473 K	Sintered 4.8 at 300 K 2.6–5.0 at 1273 K Hot pressed 4.8–6.1 at 300 K 4.1–5.0 at 1273 K 5–7	207–483	0.19	4.3–5.6	63–155 at 400 K 21–33 at 1400 K	628–1046	0.85 at 400 K (N) 0.80 at 1800 K (N)	31
SiC (CVD)	β cubic	3.21	28–44			415–441		5.5	121 at 400 K 34.6 at 1600 K	837 at 400 K 1464 at 2000 K		
Si_3N_4	α hexagonal β hexagonal	3.18 3.19	8–19	Sintered 414–650 Hot pressed 700–1000 Reaction bonded 250–345	Sintered 5.3 Hot pressed 4.1 6.0 Reaction bonded 3.6	304	0.24	3.0	9–30 at 400 K	400–1600	0.9 at 600 K (N) 0.8 at 1300 K (N)	16
TiN	Cubic	5.43–5.44	16–20			251		8.0	24 at 400 K 67.8 at 1773 K 56.9 at 2573 K	628 at 273 K 1046 at 1366 K	0.4 at 800 K (N) 0.8 at 1400 K (N) 0.5 at 2100 K (N) 0.33 at 3000 K (N) 0.8 at 1366 K (T)	135
Graphites (with grain)	Hexagonal	2.21	35–85[f]	0.48–207	0.5–1.8	1.4–34.5	0.07–0.22	0.1–19.4	1.67–518.8	711–1423		329
Cast irons	Cubic	5.5–7.8	1–7	90–1186	37–45	83–211	0.17	8.1–19.3	46–52	460		

[a]Published in: W. J. Lackey, D. P. Stinton, G. A. Cerny, L. L. Fehrenbacher, and A. C. Schaffhauser, "Ceramic Coatings for Heat Engine Materials – Status and Future Needs," *Proceedings of International Symposium on Ceramic Components for Heat Engines, October 17–21, 1983*, Hakone, Japan.
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[b]N, normal; T, total hemispherical.

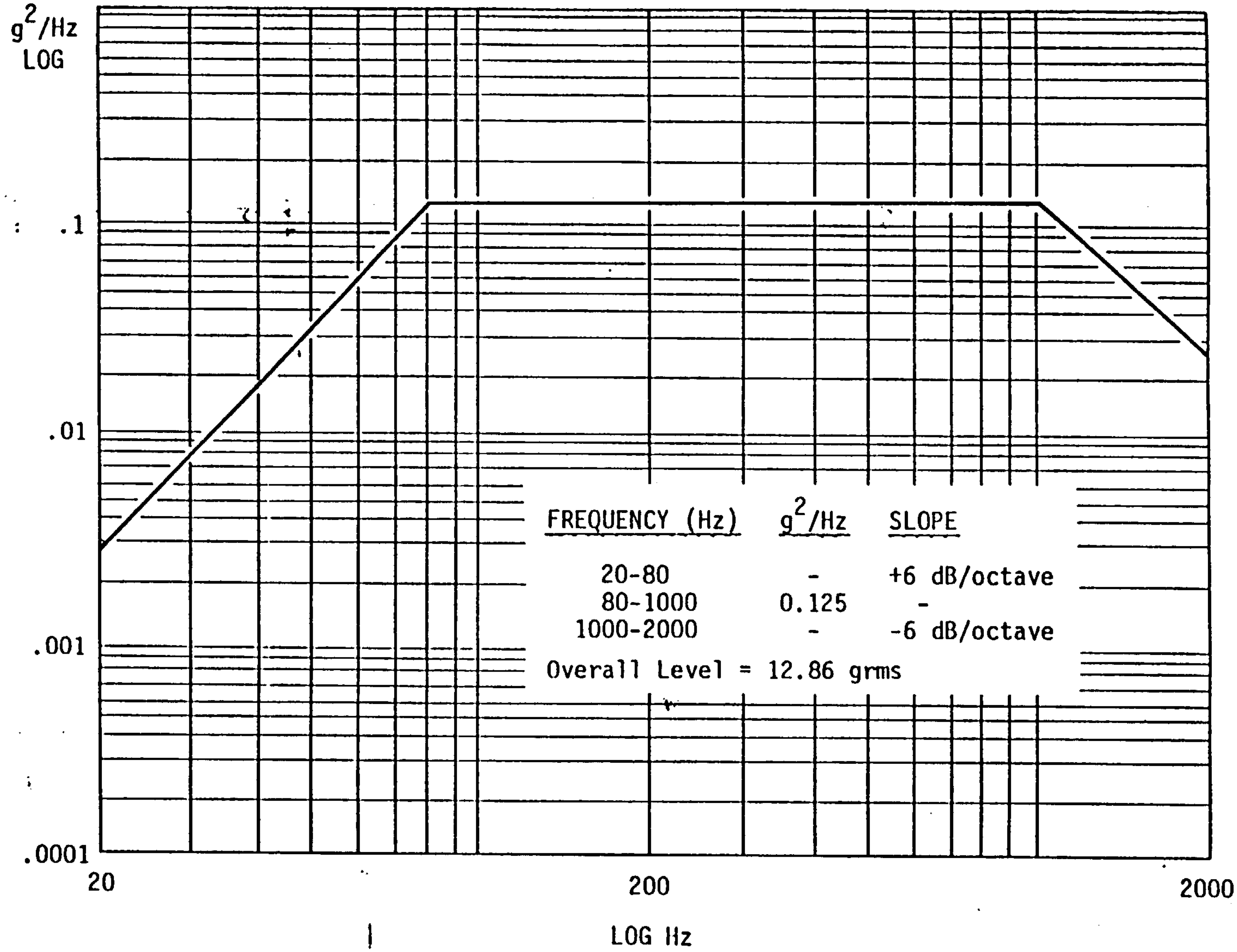
[c]Calculated using $R = k\sigma(1-\mu)/E\alpha$.

[d]Corning grade 9606.

[e]Kennametal grade K-701.

[f]Scleroscope.

Appendix B - Vibration Specifications



Random Vibration Level for Payloads Inside GAS Canisters
(40 secs/mission/axis)

Appendix C - 1991-1992 MQP Budget

Budget

1 Pressure Transducer	419.50
1 Inlet Valves	59.90
1 Outlet Valves	13.30
1 Lamp Assembly	1000.00
2 Replacement Bulbs	84.06
50 ft Thermocouple Wire	37.50
100 Ceramic Beads	22.00
2 Teflon Blocks	21.60
Ceramic Machining*	240.00
1 Hermetic Connector	103.00
1 Quartz Window	29.30
TOTAL (1992 MQP)	$2030.16

(* - price estimate)

Appendix D - Part Sheets

Part Sheet No. 1

Part Name: Teflon Backplate

Catalog Number:

Quantity Required: 5

Company Name: Plastics Unlimited

Company Address: 80 Winters Street
Worcester, MA
01609

Sales Number: (508) 752-7842

Technical Assistance Number:

Cost: $10.80

Part Information:

3" X 3" X 1" Block

Must be machined according to drawing

Part Sheet No. 2

Part Name: Quartz Window

Catalog Number:

Quantity Required: 5

Company Name: Finkenbeiner Glass

Company Address:

Waltham, MA

Phone Number: (617) 899-3138

Technical Assistance Number:

Cost: $29.30

Part Information:

3.5"D X 1/8"

Part Sheet No. 3

Part Name: Thermocouple Wire

Catalog Number: TT-K-30

Quantity Required: 50 ft

Company Name: Omega Engineering, Inc.

Company Address: P.O. Box 2284
Stamford, CT
06906

Sales Number: 1-800-826-6342

Technical Assistance Number: 1-800-872-4936

Cost: $33.50

Part Information:

Teflon Insulated

K-Type

Duplex

AWG 30

Part Sheet No. 4

Part Name: Electrical Pass-Through (Female Flange)

Catalog Number: MTC-12-FF

Quantity Required: 5

Company Name: Omega Engineering, Inc

Company Address: P.O. Box 2284
Stamford, CT
06906

Sales Number: 1-800-826-6342

Technical Assistance Number: 1-800-872-9436

Cost: $41.00

Part Information:

12 Pin

Seal Questionable

New part should be selected

Part Sheet No. 5

Part Name: Electrical Pass-Through (Male Cord)

Catalog Number: MTC-12-MC

Quantity Required: 5

Company Name: Omega Engineering, Inc.

Company Address:

P.O. Box 2284

Stamford, CT

06906

Sales Number: 1-800-826-6342

Technical Assistance Number: 1-800-872-9436

Cost: $41.00

Part Information:

same as part 4

Part Sheet No. 6

Part Name: Thermocouple Contact Pins (Gold Plated)

Catalog Number: MTC-AU-P

Quantity Required: 50

Company Name: Omega Engineering, Inc.

Company Address:

P.O. Box 2284

Stamford, CT

06906

Sales Number: 1-800-826-6342

Technical Assistance Number: 1-800-872-9436

Cost: $0.75

Part Information:

Precision Screw Machined

For electrical connector

Part Sheet No. 7

Part Name: Thermocouple Contact Sockets (Gold Plated)

Catalog Number: MTC-AU-S

Quantity Required: 50

Company Name: Omega Engineering, Inc.

Company Address:

P.O. Box 2284

Stamford, CT

06906

Sales Number: 1-800-826-6342

Technical Assistance Number: 1-800-872-9436

Cost: $1.25

Part Information:

Precision Screw Machined

For electrical connector

Part Sheet No. 8

Part Name: Thermocouple Connector Sealing Plugs

Catalog Number: MTC-HP

Quantity Required: 10

Company Name: Omega Engineering, Inc.

Company Address:

P.O. Box 2284

Stamford, CT

06906

Sales Number: 1-800-826-6342

Technical Assistance Number: 1-800-872-9436

Cost: \$0.50

Part Information:

For electrical connector

Thermocouple Connectors
Multipin Design

- Thermocouple Alloy Pins
- Air and Moisture Resistant Connection
- Rated to 392°F (200°C)
- Removable Crimp Contacts
- 20-24 AWG Stranded Wire
- Aluminum Shells
- Black Anodized Finish
- Threaded Coupling

Shown with In-Line Cord Connector with Optional Backshell Cable Clamp

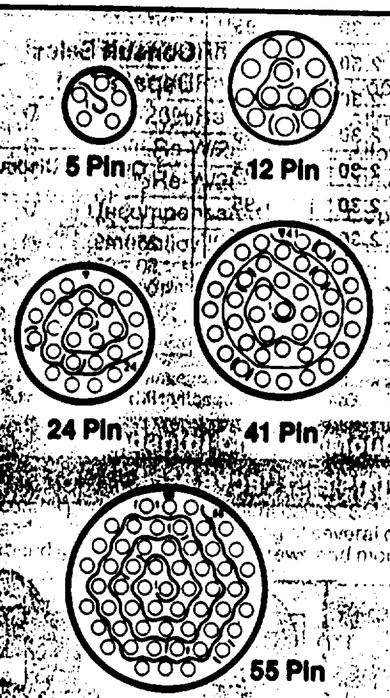
From $39

For Five Cavity Female Flanged Connector— Pins Sold Separately

ALTHOUGH MTC PINS DO NOT CARRY A MIL. SPEC. NUMBER, THEY DO MEET THE PERFORMANCE REQUIREMENTS OF MIL-C-26500E AND ARE INTERMATEABLE WITH MIL-C-26500 CONNECTORS.

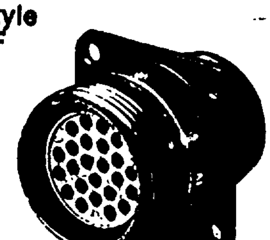
OMEGA sturdy multipin connectors provide an efficient means of joining multiwire thermocouple cables. They can be used with multiple OMEGA extension wire for rapid, convenient connections and dismantling of apparatus without handling individual sensors.

When used with the MTC Series pins the connector design utilizes a combination of resilient and rigid dielectric insulators to eliminate internal air voids and prevent the passage of air and moisture into or through the connector. Connectors can withstand ambient temperatures to 392°F (200°C), contributing to an extended connector life.



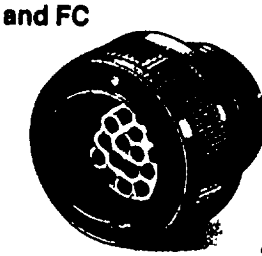
Contact cavities are identified with a ... guide line indicating cavity ...ence. The first and last cavities are numbered and every tenth cavity is bracketed.

Style FF



Flange mounted receptacle with threaded coupling. Uses sockets only.

Styles MC and FC



In-line cord connectors with threaded couplings. Style MC uses Pins, style FC uses sockets.

Multipin Connector Bodies*

Number of Cavities	MC Male Cord	Price	FC Female Cord	Price	FF Female Flanged	Price	Backshell Cable Clamp**	Price
5	MTC-5-MC	$39	MTC-5-FC	$47	MTC-5-FF	$37	MTC-5-SHL	$29
12	MTC-12-MC	41	MTC-12-FC	51	MTC-12-FF	41	MTC-12-SHL	30
24	MTC-24-MC	47	MTC-24-FC	55	MTC-24-FF	47	MTC-24-SHL	31
41	MTC-41-MC	57	MTC-41-FC	64	MTC-41-FF	56	MTC-41-SHL	32
55	MTC-55-MC	61	MTC-55-FC	73	MTC-55-FF	61	MTC-55-SHL	33

* *Contacts not included. Order from next page.*
** *Backshell cable clamps provide effective support for the cable at the male or female connector and prevent twisting and pulling.*

ORIGINAL PAGE IS OF POOR QUALITY

Crim
Cont
Acce
High

OMEGA pu... are manufa... alloy materi... easy identif... crimp termi... connector a... the appropr... insertion to... removed fro... assembly u... tool. Sealin... seal unuse... socket.

To Order
Specify Cor... and Backsh...
Example: C... for 6 type... thermocc...
Male Conne...
1. Body: MT...
2. Pins: (+)...
(−)...
3. Backshel...
Female Cor...
1. Body: MT...
2. Sockets:
(+) Pos. ...
(−) Neg. ...
3. Backshel...

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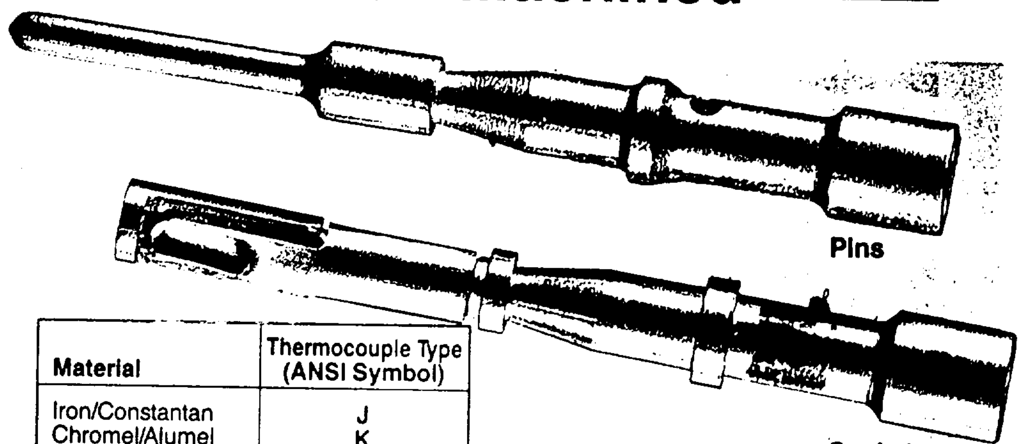
Thermocouple Contacts
Precision Screw Machined

MADE IN USA



Shown 6x Actual Size

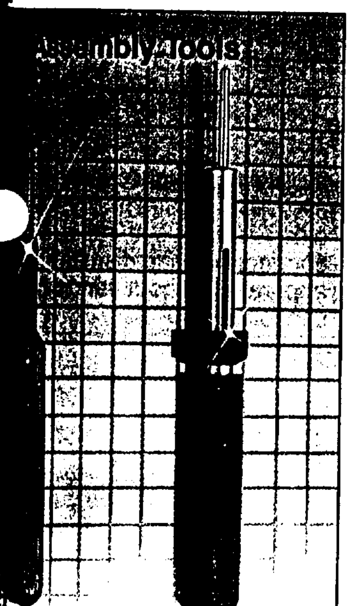
G

Crimp-Type Attachment
Contacts are Color Coded
Accessories Available
High Performance Design

...GA push-in crimp style contacts ...anufactured from thermocouple ...materials and color-coded for ...identification. Contacts are ...terminated outside the ...ector assembly and inserted into ...ppropriate cavity by means of an ...ion tool. They can be readily ...ved from the connector ...mbly using a special removal ... Sealing plugs are available to ...nused positions in lieu of pin or ...

Material	Thermocouple Type (ANSI Symbol)
Iron/Constantan	J
Chromel/Alumel	K
Copper/Constantan	T
Chromel/Constantan	E

...ssembly Tools



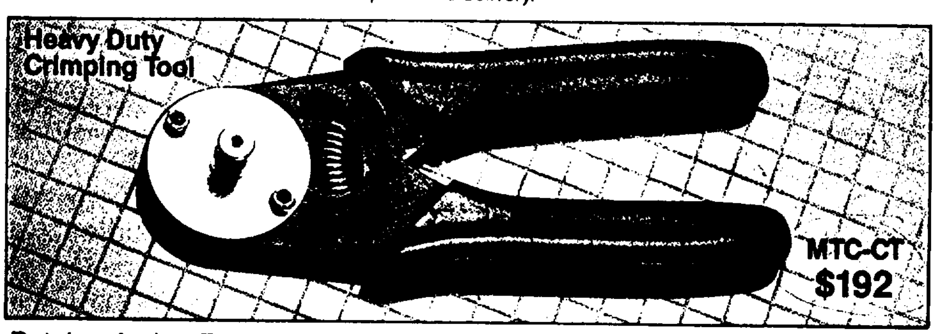
...rtion Tool
...TC-IT
...$24

Removal Tool
MTC-RT
$55

Thermocouple Alloy and Gold Plated Copper Contacts for Multipin Connectors

Alloy Type	Pins (Male)	Coding Color Letter	Price Each	Sockets (Female)	Coding Color Letter	Price Each
Iron (+)	MTC-IR-P	BLK M	$15	MTC-IR-S	BLK M	$25
Constantan (–)	MTC-CO-P	YEL N	25	MTC-CO-S	YEL N	25
Copper (+)	MTC-CU-P	RED C	20	MTC-CU-S	RED C	20
Chromel (+)	MTC-CH-P	WHT P	17	MTC-CH-S	WHT P	25
Alumel (–)	MTC-AL-P	GRN R	17	MTC-AL-S	GRN R	25
*Gold Plated (Uncompensated)	MTC-AU-P	Color Bands RED, YEL, BRN	.75	MTC-AU-S	Color Bands RED, BLU, BLK	1.25

Sealing Plug, model MTC-HP, $.50 each
**For use with non-thermocouple wire in same body.*
Gromments available. Consult sales for price and delivery.



Ratchet Action Easy-to-Use!
Specially designed MS standard crimping tool MUST be used to properly crimp wires to pins and sockets. Ratchet action ensures a complete crimp every time.

Important Notes

1. MS Standard Assembly Tools are required to properly crimp and assemble connectors. Order with first purchase.
2. Match Pins and Sockets to Thermocouple Alloys
Example: A 12 cavity connector carries 6 thermocouple circuits (pairs) requiring: 6 positive alloy pins or sockets and 6 negative alloy pins or sockets per body.
3. Order bodies in Mating Pairs. Style MC mates with both style FF and style FC.
4. Backshell Cable Clamps are recommended with each cord style connector.

...rder
...ly Connector Body, Contacts ...ackshell (See Note 1).
...ple: Cord to Cord connectors ...6 type J (Iron-Constantan) ...mocouple circuits (pairs).
...Connector Assembly
...y: MTC-12-MC
...(+) Pos. Alloy, MTC-IR-P, 6 ea.
... Neg. Alloy, MTC-CO-P, 6 ea.
...l: MTC-12-SHL
...onnector Assembly
...y: MTC-12-FC
...ckets:
...) Pos. Alloy, MTC-IR-S, 6 ea.
...Neg. Alloy, MTC-CO-S, 6 ea.
...kshell: MTC-12-SHL

Part Sheet No. 9

Part Name: Ceramic Beads

Catalog Number:

Quantity Required: 20

Company Name: Omega Engineering, Inc.

Company Address:

P.O. Box 2284

Stamford, CT

06906

Sales Number: 1-800-826-6342

Technical Assistance Number: 1-800-872-9436

Cost: $22.00 (for 100)

Part Information:

For Thermocouple Array

For Backface thermocouple

Part Sheet No. 10

Part Name: EPX Series Miniature Threaded Pressure Transducer

Catalog Number: EPX12 - 10 - 25 A Z

Quantity Required: 5

Company Name: Entran Devices, Inc.

Company Address: 10 Washington Avenue
Fairfield, NJ
07004

Sales Number: 1 (800) 635-0650 Bob Levy

Technical Assistance Number: same

Cost: $415 + 4.50 shipping

Part Information:

25 psia

12V excitation (nonstandard)

Option Z 0C to 60C Compensated Temperature Range

SPECIFICATIONS
EPX-10

RANGE psi	5	*10	15	25	*50	*100	*250	*500	*1000	2500	5000
OVERRANGE psi	50	50	50	50	100	200	500	1000	2000	4000	6000
SENSITIVITY (nom.) mV/psi	3	2.5	2	2	1.5	1.2	.5	.25	.12	.05	.025
SENSITIVITY (nom.) mV F.S.	15	25	30	50	75	125	125	125	125	125	125
[1]RES. FREQUENCY nom.	45KHz	50KHz	65KHz	65KHz	75KHz	80KHz	120KHz	150KHz	200KHz	300KHz	450KHz
COMB. NON-LIN. & HYST.	±1%F.S.					±¾%F.S.	±½%F.S.				
TEMP. SHIFT ZERO	±1mV/100°F			±2%F.S./100°F		±1½%F.S./100°F					
TEMP. SHIFT SENS.	±2%/100°F (±3½%/100°F for EPX6-)										
g SENS. nom. %F.S./g	.015	.007	.0048	.003	.0016	.0012	.0006	.0004	.0003	.0002	.0001

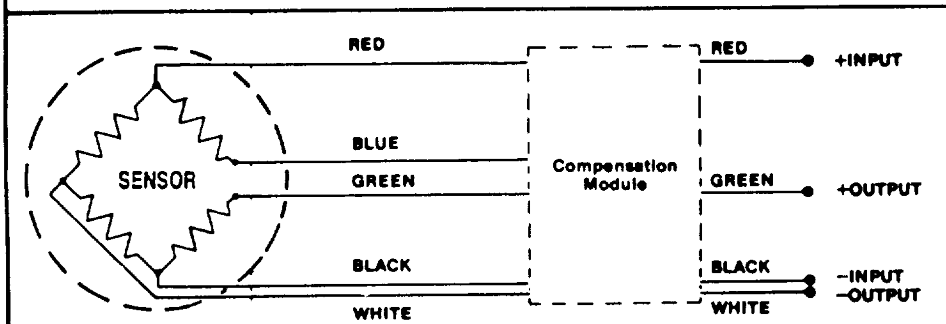
* "OFF-THE-SHELF" STOCK IN EPX-10W-10, -50, -100, -250, -500, AND -1000.

SPECIFICATIONS COMMON TO ALL RANGES AND THE METRIC SERIES

	EPX-	EPX6-	CUSTOM OPTIONS[2] (see Selection Manual)
EXCITATION	10 VDC	6 VDC	3 to 15 VDC or VAC
IMPEDANCE INPUT	1200 Ω nom. typ. (350 Ω min.)	700 Ω nom. typ. (350 Ω min.)	200 Ω to 2500 Ω nom.
IMPEDANCE OUTPUT	350 Ω nom.	350 Ω nom.	120 Ω to 500 Ω nom.
REPEATABILITY	±0.25%	±0.25%	±0.1%
RESOLUTION	INFINITE		
COMPENSATED TEMP.	70°F to 170°F (21°C to 77°C) OPTION Z 32°F to 140°F (0°C TO 60°C)		Ranges within: −100°F to 450°F −73°C to 230°C
OPERATING TEMP.	−40°F to 250°F (−40°C to 121°C)		−100°F to 500°F (−73°C to 260°C)
ZERO OFFSET (70°F 21°C)	±10mV typ.	±10mV typ.	±1%F.S.

[1] Useful Frequency Range is 20% of Resonant Frequency. [2] Custom options may alter other specifications and are not necessarily available on all models and in all combinations. Contact Entran directly for you specific requirements.

WIRING DIAGRAM



OPTION "/5"

5 WIRE OUTPUT FOR ZERO OFFSET ADJUST

+Output is split into 2 wires, Green and Blue. User connects a 25 Ω potentiometer across Green and Blue with center tap as +output. Example: EPX-10W/5-

METRIC SERIES
EPX-M5

RANGE	bar	0.35	0.7	1	1.5	3.5	7	15	35	70	150	350
OVERRANGE	bar	3.5	3.5	3.5	3.5	7	14	30	70	140	240	420
SENSITIVITY (nom.)	mV/bar	40	35	30	30	20	17	8	3.5	1.7	.8	.35
	mV F.S.	15	25	30	45	75	125	125	125	125	125	125
[1] RES. FREQUENCY nom.		45KHz	50KHz	65KHz	65KHz	75KHz	80KHz	120KHz	150KHz	200KHz	300KHz	450KHz
COMB. NON-LIN. & HYST.		±1%F.S.					±¾%F.S.	±½%F.S.				
TEMP. SHIFT	ZERO	±1mV/50°C			±2%F.S./50°C		±1½%F.S./50°C					
	SENS.	±2%/50°C (±3½%/50°C for EPX6-)										
g SENS. nom. %F.S./g		.015	.007	.0048	.003	.0016	.0012	.0006	.0004	.0003	.0002	.0001

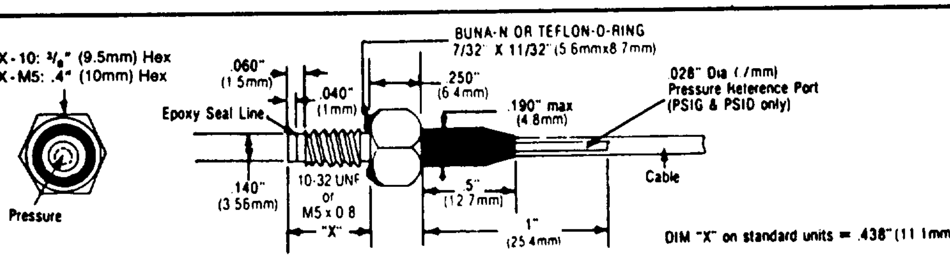
[1] Useful Frequency Range is 20% of Resonant Frequency.

MOUNTING STYLES

EPX-10 or **EPX-M5** } External Compensation Module

EPX-10I or **EPX-M5I** } Internal Compensation (Module within Housing)

EPX-10: 3/8" (9.5mm) Hex
EPX-M5: .4" (10mm) Hex

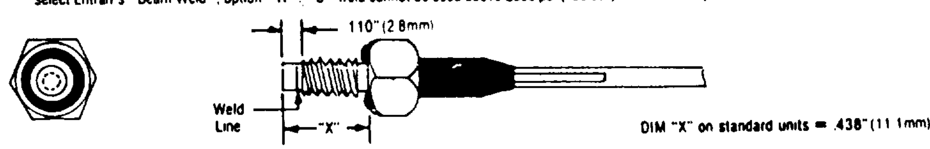


EPX-10U
EPX-10W
or
EPX-M5U
EPX-M5W
} External Compensation Module

EPX-10IU
EPX-10IW
or
EPX-M5IU
EPX-M5IW
} Internal Compensation (Module within Housing)

FOR WATER OR CORROSIVE FLUIDS COMPATIBLE WITH 304SS

For water usage less than 8 hours continuous, the standard epoxy seal is adequate. For water usage more than 8 hours or in fluids which normally swell epoxy, select Entran's "Braze Weld", option "U". For use in corrosive media compatible with 304SS, Biomedical or Food Processing work, select Entran's "Beam Weld", option "W". "U" weld cannot be used above 2500 psi (150 bar) and has a temperature limit of 300°F (150°C).

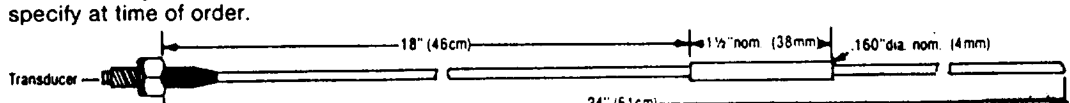


CUSTOM SCREW LENGTH OPTION

Standard EPX units are supplied with DIM "X", the distance from sealing surface to diaphragm, as 7/16" (11.1mm). You can order any length you desire between 0.250" and 1.50" (6.3mm and 40mm). Just add the custom "X" dimension to the model number as shown on the back page and consult the price list for the additional charge. All EPX-10 units have "X" expressed in inches and EPX-M5 units have "X" expressed in mm.

LEAD WIRES & COMPENSATION MODULE

All units are supplied with 24"(61cm) of Teflon insulated shielded cable with the Compensation Module located 18" (46cm) from the transducer (except for internal compensation units). The module is supplied with each unit wired into the leads. If you desire longer lead lengths or module location other than 18" (46cm), please consult price list and specify at time of order.



TO ORDER AN "EPX" SERIES PRESSURE TRANSDUCER

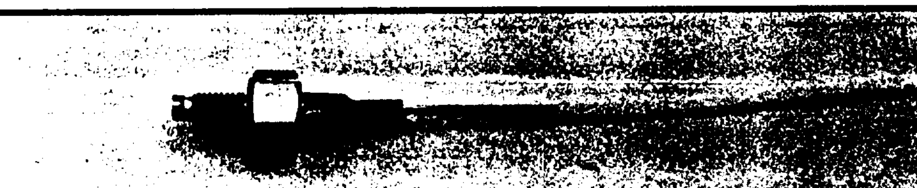
1. Select Desired Input Voltage Option EPX or EPX6.
2. Select Desired Mounting Style in Standard or Metric Versions.
3. Select Welded Version If Required.
4. Select Pressure Range.
5. Specify Pressure Reference Gauge, Absolute, Differential or Sealed Gauge. If Not Specified, Unit Will Be Supplied as Gauge.
6. Specify Custom Thread Length If Required.

EPX	—10	U	—	100	G	Z	— (XX)
SERIES	STYLE	WELDED OPTION		PRESSURE RANGE	REFERENCE: G-Gauge (Relative) D-Differential (Wet/Dry or Dry/Dry) S-Sealed Gauge A-Absolute (Gauge if not specified)	OPTION	CUSTOM THREAD LENGTH

Examples:

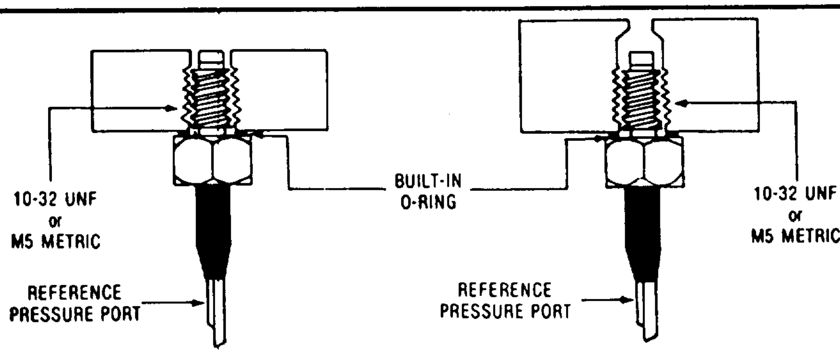
EPX-10-50	Standard 10-32 UNF Thread, 50 PSIG range.
EPX-M5-3.5	M5 Metric Thread, 3.5 bar range, relative (gauge).
EPX-10U-100A-(.37)	Braze Welded 10-32 UNF Version with 100 PSIA range and custom thread length of "X" = 0.37".
EPX-M5W-7-(10)	Beam Welded M5 Metric Thread with 7 bar range and custom thread length of "X" = 10mm.
EPX6-101-5000	EPX with 6V Excitation option on 10-32 UNF Threaded Housing with Internal Compensation Module, 5000 psig.

ACTUAL SIZE



TYPICAL INSTALLATION

EPX-10 or EPX-M5



INSTALLATION TORQUE

Pressure Range	In-Lbs	Meter-Newton
0 to 50 psi 0 to 3.5 bar	5	0.6
60 to 500 psi 4 to 35 bar	10	1.2
600 to 5000 psi 40 to 350 bar	15	1.8

Part Sheet No. 11

Part Name: Argus Model 44 Heat Lamp

Catalog Number:

Quantity Required: 5

Company Name: Argus International

Company Address:

Hopewell, NJ

08525

Sales Number: (609) 466 - 1677

Technical Assistance Number:

Cost: $1000

Part Information:

Part Sheet No. 12

Part Name: Replacement Bulb

Catalog Number: 2002-00-013

Quantity Required: as needed + 4 spares

Company Name: Argus International

Company Address:

Hopewell, NJ

08525

Sales Number: (609)466-1677

Technical Assistance Number:

Cost: $42.07

Part Information:

Replacement bulb for heat lamp

Part Sheet No. 13

Part Name: Ceramic Machining

Catalog Number:

Quantity Required: 4

Company Name: Bomas Machine Specialties, Inc.

Company Address: 334 Washington St

Somerville, MA

02143

Sales Number: (617) 628-3831 fax(617) 628-6108 Joe Annese

Technical Assistance Number:

Cost: $240 total (estimate)

Part Information:

drilling 1/8"D hole in ceramic plate

Part Sheet No. 14

Part Name: Ceramic Plate

Catalog Number:

Quantity Required: 4

Company Name: Materials Science Dept. (@ WPI)

Company Address: Washburn

Sales Number:

Technical Assistance Number:

Cost: FREE

Part Information:

Aluminum Oxide

2.5" X 2.5" X 1/8"

Part Sheet No. 15

Part Name: NUPRO "C" Series Check Valve

Catalog Number: SS-4C-VCR-10

Quantity Required: 4

Company Name: Nupro Company

Company Address:

4800 East 345th Street

Willoughby, Ohio

44094

Sales Number: (617)272-8270 Phil Burma

Technical Assistance Number:

Cost: $59.90

Part Information:

see next page

NUPRO
"C" & "CA" SERIES CHECK & ADJUSTABLE IN-LINE RELIEF VALVES

FLOW CAPACITY

[illegible]	[illegible]	[illegible]
[illegible]		
10	2.21	0.51
50	6.12	1.13
100	10.85	1.60
[illegible]		
10	6.50	1.49
50	17.98	3.32
100	31.87	4.70
[illegible]		
10	20.33	4.65
50	56.23	10.39
100	99.68	14.70
[illegible]		
10	22.96	5.25
50	63.49	11.74
100	112.56	16.60
[illegible]		
10	5.14	1.17
50	14.01	2.62
100	24.84	3.70

NOTE: Higher cracking pressures may reduce the flow rate

MATERIALS

Body, Poppet, Nuts & Ferrules — Brass, 316 stainless steel, Monel, and aluminum.

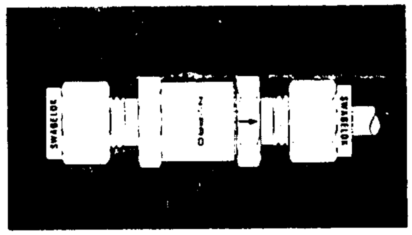
Spring — Type 302 stainless steel in all valves, except Monel valves use Monel springs.

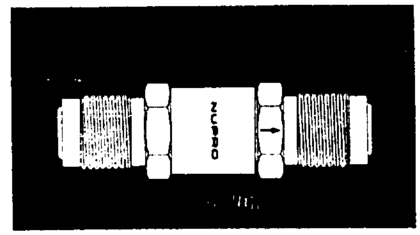
Gasket "CA" Series — TFE coated 316SS; TFE coated Monel in Monel valves. "6C" & "8C" Series (with 50 through 100 PSI springs only) — TFE coated 316SS in stainless steel valves; TFE coated Monel in Monel valves; TFE coated aluminum in brass and aluminum valves.

O-Ring — Buna "N" is standard in brass and aluminum valves. Viton is standard in stainless steel and Monel valves. Many different types of elastomer O-Rings are stocked by NUPRO Company for specialized applications. Due to the hardness of TFE, O-Rings of this material will not seal leak-tight except with very high back pressure. TFE O-Rings are useful on cycling pump applications where gas tight sealing is not required and pressure surges are common.

Adjusting Screw, Lock Screw ("CA" Series Only) — brass, aluminum, and 316 stainless steel valves use 316 stainless steel. Monel valves use Monel.

Lubricants used: *For wetted parts — Silicone base lube and molybdenum disulfide base dry film. For non-wetted parts — Molybdenum disulfide base dry film.*





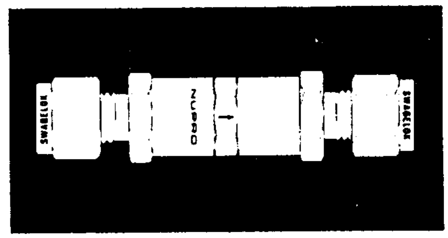


TABLE OF DIMENSIONS

[illegible]	[illegible]		[illegible]		[illegible]			
-2C-	.094	2.4	1/8 SWAGELOK	1/8 SWAGELOK	2 7/32	31/32	7/16	5/8
-2C2-	.125	3.2	1/8 Male NPT	1/8 Male NPT	1 23/32	31/32	—	5/8
-2C4-	.187	4.7	1/8 Female NPT	1/8 Female NPT	2 1/16	—	—	5/8
-4C-	.187	4.7	1/4 SWAGELOK	1/4 SWAGELOK	2 13/32	31/32	9/16	5/8
-4C-VCR-	.187	4.7	1/4 VCR	1/4 VCR	2 7/32	31/32	—	5/8
-4C1-	.187	4.7	1/4 Male NPT	1/4 SWAGELOK	2 1/4	31/32	9/16	5/8
-4C2-	.187	4.7	1/4 Male NPT	1/4 Male NPT	2 3/32	31/32	—	5/8
-4C4-	.187	4.7	1/4 Female NPT	1/4 Female NPT	2 5/32	—	—	3/4
-4CA-	.156	4.0	1/4 SWAGELOK	1/4 SWAGELOK	3 7/32	1 13/16	9/16	5/8
-4CA1-	.156	4.0	1/4 Male NPT	1/4 SWAGELOK	3 1/16	1 13/16	9/16	5/8
-6C-	.281	7.1	3/8 SWAGELOK	3/8 SWAGELOK	3 7/32	1 21/32	11/16	7/8
-6C2-	.359	9.1	3/8 Male NPT	3/8 Male NPT	2 25/32	1 21/32	—	7/8
-6C4-	.359	9.1	3/8 Female NPT	3/8 Female NPT	3	—	—	7/8
-8C-	.359	9.1	1/2 SWAGELOK	1/2 SWAGELOK	3 7/16	1 11/16	7/8	7/8
-8C-VCR-	.359	9.1	1/2 VCR	1/2 VCR	3 9/16	2 1/16	—	7/8
-8C2-	.359	9.1	1/2 Male NPT	1/2 Male NPT	3 5/32	1 21/32	—	7/8
-8C4-	.359	9.1	1/2 Female NPT	1/2 Female NPT	3 9/16	—	—	1 1/16
-10C-	.359	9.1	5/8 SWAGELOK	5/8 SWAGELOK	3 9/16	1 13/16	1	1 1/16
-6C-MM	.187	4.7	6mm SWAGELOK	6mm SWAGELOK	2 13/32	31/32	9/16	5/8
-10C-MM	.281	7.1	10mm SWAGELOK	10mm SWAGELOK	3 7/32	1 21/32	11/16	7/8
-12C-MM	.359	9.1	12mm SWAGELOK	12mm SWAGELOK	3 7/16	1 11/16	7/8	7/8

5

[1] For a complete ordering number:

a. Add B for brass, SS for 316 stainless steel, A for aluminum and M for Monel as a prefix to the catalog number. Example: SS-2C-

b. For "C" Series valves, add 1/3, 1, 10, or 25 as a suffix to the catalog number for the desired cracking pressure. Special springs to 100 PSI cracking pressures are available. Example: B-4C-1

c. For "CA" Series valves, add 3 for 3 to 50 PSI cracking pressures, 50 for 50 to 150 PSI, 150 for 150 to 350 PSI, or 350 for 350 to 600 PSI as a suffix to the catalog number for the desired cracking range. Example: SS-4CA-3

[2] Dimensions shown with SWAGELOK nuts finger-tight, where applicable. All dimensions in inches — for reference only, subject to change.

NUPRO COMPANY • 4800 E. 345th Street • Willoughby, Ohio 44094

Part Sheet No. 16

Part Name: NUPRO "P" Series Purge Valve

Catalog Number: SS-4P-4M

Quantity Required: 4

Company Name: Nupro Company

Company Address:

4800 East 345th Street

Willoughby, Ohio

44094

Sales Number: (617)272-8270 Phil Burma

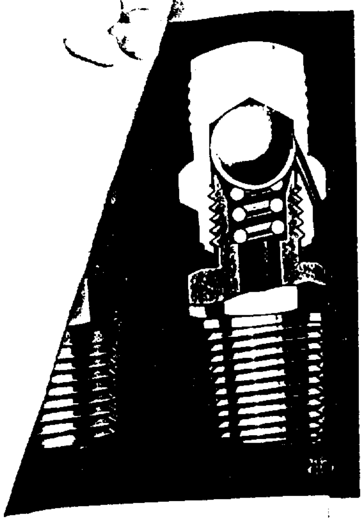
Technical Assistance Number:

Cost: $13.30

Part Information:

see next page

R□ PURGE VALVES



'URPOSE

AUPRO "P" Series Purge Valves e ntended to be used as manil bled, vent, or drain valves r numerous instruments ad systems.

OPERATION

One-quarter turn with a wrench frn finger-tight should be used to obtn a leak-tight closure on first mai-up. After that, snugging witha wrench will insure closure to e rated pressure. Purge valves usina TFE ball require only finger pressle for leak-tight shut-off.

APPLICATIONS

Bleed or vent gases or liquids fron gauges, instruments and pressurl-ed containers • Vent air from high points in hydraulic systems • Bleed liquid from low points in gas or steam systems.

SPECIAL FEATURES

Compact • Quarter turn operation • Safety engineered • Discharge directed away from operator • Variety of materials • Large choice of end connections • Repetitive, leak-tight shut-off • Valves with TFE balls have a removable cap for easy ball replacement • Higher pressure all-metal valves have the knurled cap permanently assembled.

TECHNICAL DATA

VALVE TYPE	PRESSURE RATING	MAXIMUM TEMPERATURE RATING
316 stainless steel	4000 PSI (27,500 KPa)	600°F (315°C)
Brass	3000 PSI (20,600 kPa)	400°F (204°C)
Monel	4000 PSI (27,500 kPa)	450°F (232°C)
Aluminum	2000 PSI (13,700 kPa)	400°F (204°C)
Carbon Steel	3000 PSI (20,600 kPa)	600°F (315°C)
Valves with TFE ball	200 PSI (1350 kPa)	350°F (176°C)

FLOW CAPACITY

	MAXIMUM FLOW	
PRESSURE DROP TO ATMOSPHERE	AIR SCFM	WATER GPM
10	0.60	0.14
50	1.64	0.30
100	2.92	0.43

Orifice size of discharge: 1/16" (1.6mm)

MATERIALS

Body, Cap, Nut and Ferrules—Brass, 316 stainless steel, Monel, aluminum and carbon steel.
Ball—Type 316 stainless steel in all valves, except stainless steel valves use a 316 stainless steel poppet and Monel valves use a Monel ball.
Spring—Type 302 stainless steel in all valves except Monel valves use a Monel spring.
NOTE: Any NUPRO Purge Valve may be supplied with a TFE ball on request.

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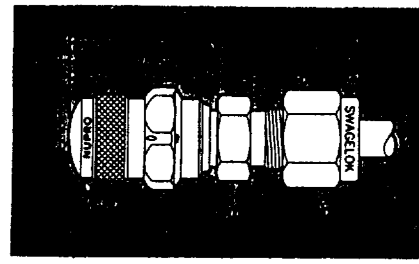
TABLE OF DIMENSIONS

PURGE VALVES CATALOG NUMBER[1]	END CONNECTION	DIMENSIONS			
-4P-2	1/8 SWAGELOK	1 27/32	7/16	1/2	5/8
-4P-4	1/4 SWAGELOK	1 15/16	9/16	1/2	23/32
-4P-6	3/8 SWAGELOK	2 1/32	11/16	5/8	25/32
-4P-2F	1/8 Female NPT	1 17/32	—	9/16	17/32
-4P-4F	1/4 Female NPT	1 23/32	—	3/4	23/32
-4P-2M	1/8 Male NPT	1 19/32	—	1/2	3/8
-4P-4M	1/4 Male NPT	1 25/32	—	9/16	9/16
-4P-6M	3/8 Male NPT	1 13/16	—	11/16	9/16
-4P-4T	1/4 Straight Tube	1 27/32	—	1/2	5/8
-4P-6T	3/8 Straight Tube	1 29/32	—	1/2	11/16

[1]For a complete ordering number, add B for brass, SS for 316 stainless steel, M for Monel, A for Aluminum and S for carbon steel as a prefix to the catalog number.
Examples: S-4P-4M, B-4P-4.
[2]Add — TFE as a suffix if a TFE ball is needed.
Example: SS-4P-4M-TFE.
[3]Dimensions shown with SWAGELOK nuts finger-tight, where applicable. All dimensions in inches — for reference only, subject to change.



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